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CLIMATE CHANGE

HEARINGS

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDRED NINTH CONGRESS

FIRST SESSION

TO

RECEIVE TESTIMONY REGARDING THE CURRENT STATE OF CLIMATE CHANGE SCIENTIFIC RESEARCH AND THE ECONOMICS OF STRATEGIES TO MANAGE CLIMATE CHANGE

JULY 21, 2005

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CLIMATE CHANGE

THURSDAY, JULY 21, 2005

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

The committee met, pursuant to notice, at 10:06 a.m., in room SH–216, Hart Senate Office Building, Hon. Pete V. Domenici, chairman, presiding.

OPENING STATEMENT OF HON. PETE V. DOMENICI, U.S. SENATOR FROM NEW MEXICO

The CHAIRMAN. The hearing will please come to order. First, let me thank everyone who is here today. I am sure you know that this is a very significant hearing and a lot of people in the audience have strong feelings about it. But we are not here for any show of strength by anybody in the audience. We know you are here, but we do not need any audience participation. And so I hope you will accommodate us in that regard.

I circulated a short list reflecting the fact that we are going to consider today, if we can—if we get twelve people, I am going to say it now, so if that happens, Senator Bingaman, if it is noted at any time, then we are going to proceed with the five pending nominees. I think you are all aware of them, but in case you are not, I would ask the staff to circulate to you their names.

If any Senators want any discussion on them, I would appreciate it if you would indicate that to me quickly, because as soon as we have requisite Senators, I am going to ask Senator Bingaman to move with reference to them. For the witnesses, that is just our own regular business.

I want to first thank the witnesses for taking time off their busy schedules to come here to provide us with their views. I commented to Senator Bingaman, when the energy bill was being considered on the floor, to have this hearing. It will not be the last hearing on this subject, but certainly for our committee, it is the first and it is very important.

At the time we discussed this, Senator Bingaman and I were engaged in serious discussions about what we might agree should be done about the issue of climate change. I have come to accept that something is happening with the earth's climate. I am aware that many in the scientific community are warning us that something needs to be done.

I am also aware that there are other qualified members of the scientific community who do not share those views, and probably even more who are concerned that anything we do will significantly affect our economy and even our way of life, and also suggest that maybe whatever we do will not have any impact. So as I said, we are going to have additional hearings, and hear from those witnesses who have different views from what we are going to hear today.

I believe that prudence warns that we consider this issue, that we hear from scientists, and we hear from economists about exactly what the role of humans is in all of this, and what the impact will be if we decide to address it. And what it might be if we decide to do nothing. So what, how, who, and when seem, to me, to be questions that have to be answered in my mind. These are the questions that this hearing and subsequent hearings will help me answer. That is what, how, who, and when.

With that, we are going to begin the search for answers. Many already think the answers are there, and that we should have already drawn conclusions and acted. I think, however, everyone knows this is a very, very important scientific issue, and that the results are very important and solutions are very important.

I hope this committee understands that we intend to move ahead with a series of activities that will put us into the middle of this issue, and then we will see how it comes out.

With that, I yield to my friend and colleague from New Mexico, Senator Bingaman, who has an opening statement.

[The prepared statements of Senators Corzine, Bunning and Feinstein follow:]

PREPARED STATEMENT OF HON. JON S. CORZINE, U.S. SENATOR FROM NEW JERSEY

Mr. Chairman, I would first like to thank you for holding this hearing on one of the most pressing issues facing our planet—climate change. And Senator Bingaman, you have been a major proponent of effective climate change policy and I want to thank you for your leadership in this area.

The world's leading scientists have linked the burning of fossil fuels to global warming that threatens our environment, our health, and our future. The threat of global warming is real and needs to be addressed. I am pleased that a resolution put forth by Senator Bingaman expressing the sense of the Senate that the Senate must take action to address climate change recently passed on a bipartisan basis. While this is a step in the right direction, it is absolutely imperative that Congress take bigger leaps forward to implement a comprehensive, thoughtful policy that effectively addresses global warming

Massive amounts of evidence show that average global temperatures are rising. Part of this increase is natural. Temperatures do vary over short and long terms. Many opponents of climate change legislation argue incorrectly that the changes in global temperature are due to these naturally occurring fluctuations. In an attempt to bolster their claim they cite a "medieval heat wave." They fail to mention, however, that scientific documentation distinguishes between natural climate variability and human induced climate change. Scientists have conducted a number of studies that indicate the climate change observed over the 20th century is due to a combination of factors—including changes in solar radiation, volcanic activity, land-use change, and increases in atmospheric greenhouse gases. Of these, the increase in greenhouse gases has been the dominant driver of climate change over the past few decades. And we have the technology to change that. If we have the will, we can lower the amount of greenhouse gasses released into our environment.

I have long been a proponent of legislation that would counter this problem and encourage reductions of greenhouse gas emissions. My advocacy on behalf of climate change legislation is not limited to the current Congress. Senator Brownback and I led the way to passing a greenhouse gas registry and reporting amendment to the Energy Bills in the 107th and 108th Congresses. M. Chairman, the current voluntary programs encourage reductions from only a small group of industry leaders, and have little to no effect on most of the economy. Despite these well-intended programs, greenhouse gas emissions have risen on average one percent per year for the last several years. We can do better. I am disappointed that the bill passed by the

House this Congress included absolutely no language concerning climate change and the Senate bill did not include enough. The lack of effective climate change policy is big part of why I voted against the Senate Energy Bill.

The potential effects of global warming are dire for my state. If we do not control climate change, New Jersey could face a receding coastline along the shore, loss of habitat in our beautiful beach towns like Cape May, and more extreme weather events such as storms and flooding. This will also impact New Jersey's economy. If our beaches are threatened, and our coastline damaged, New Jersey will see an economic impact of catastrophic proportions. Our second largest industry, tourism, will be devastated.

This is an issue for New Jersey and the rest of the United States, but it is also an issue for the world. In fact, the United States lags far behind all of the G8 countries in addressing climate change. Thankfully, British Prime Minister Tony Blair made this issue central in the meeting of the Group of 8. The science is increasingly clear that greenhouse gas emissions produced by humans are changing the earth's climate. It is also eminently clear the rest of the industrialized world understands the danger of this problem. Unless Congress acts, the effects of global warming may be devastating to the worldwide economy and environment. Recognition by the Senate that global warming is indeed a problem is a meaningful and important first step. However, we can not stop here. Congress needs to act boldly and pass additional legislation that counters this problem. History will surely judge this body harshly if we fail to do so.

Again, I thank the Chairman and Ranking Member for allowing this Committee the chance to hear from these witnesses before us about this crucial topic and I look forward to their testimonies.

Prepared Statement of Hon. Jim Bunning, U.S. Senator From Kentucky

Mr. Chairman, thank you. I look forward to the hearing today to discuss the science behind the changes in our planet's climate. We have all heard from many scientists about disputes over the scientific evidence. We could all debate the science of climate change all day and still not agree on how nature has worked to warm the earth and what role humans play, if any, in that warming.

We need to be careful of moving too quickly in addressing climate change. Some groups have proposed mandatory caps; I do not believe they are the answer. But I think it is clear from the comments of the witnesses before the committee today that the scientific consensus—at least in this room—is that the most important action that can be taken is to immediately move to low emission technology and improve energy efficiency.

This is precisely what we have done in the Senate. We have been addressing the climate issue with a variety of immediate-impact policies. I have authored bills and fought for provisions in the energy bill to expand Clean Coal Technology. Over half of our nation's electricity comes from coal power plants and adopting new and cleaner technology would lead to significant emissions reductions. In fact, the United States is expected to reduce its greenhouse gas emissions by 14% by 2012 without any new regulations on emissions.

We have seen good results in improving energy efficiency in the last decade. Since 1990, U.S. industry has improved its energy efficiency by 20%. Our automobiles are becoming more efficient also, running at a higher fuel efficiency today than they did just a few years ago.

I thank the witnesses for appearing before the committee today and appreciate their comments. I look forward to continuing the conversation on this issue and discussing the entire scope of climate science.

Prepared Statement of Hon. Dianne Feinstein, U.S. Senator From California

Mr. Chairman, I would like to begin by thanking you and Senator Bingaman for holding this hearing. I am extremely pleased that Senator Domenici, in particular, has recognized that climate change is happening and that it is time we do something about it.

I hope that this hearing provides the answers that some of my colleagues are looking for in order to pass a bill that will establish a mandatory cap on greenhouse gas emissions.

As many of my colleagues know, I was extremely disappointed that the McCain/Lieberman amendment to the energy bill failed. I believe that this country must act aggressively today to reduce the impacts of global warming.

And I think the McCain/Lieberman proposal provides the legislative framework we need to address climate change.

And the reason I believe that is because it is the only policy out there that has a real, mandatory cap on greenhouse gas emissions.

The scientists here today will describe what "business as usual" will mean in terms of global warming. But I would like to talk about the impacts of inaction and the huge costs of inaction on my state of California.

Since 1900, California has warmed by 2 degrees Fahrenheit. Annual precipitation has decreased over much of the state—by 10 percent to 25 percent in many areas. The Environmental Protection Agency estimates that the temperature in California could rise by as much as 5 degrees by the end of this century if the current global warming trends continue.

Increased temperatures will impact the State's water supplies. The Sierra Nevada snowpack provides the largest source of water for California. The snowpack equals about half the storage capacity of all of California's man-made reservoirs. It is estimated that the shrinking of the snowpack could eliminate the water source for 16 million people—equal to all of those in the Los Angeles Basin.

We have already begun to see a decrease in the Sierra Nevada snowpack due to warmer winter storms that bring more rain than snow and also cause premature melting of the snowpack.

If just a third of the snow pack is lost, it would mean losing enough water to serve 8 million households. So this is really a major problem.

Even if we take strong action now to reduce our greenhouse gas emissions, it is estimated that 27 percent snowpack will remain in the Sierras at the end of the century.

However, if we do nothing to reduce our greenhouse gas emissions, there will only be 11 percent of the snowpack left in the Sierras at the end of the century. This will be catastrophic not only to California's water supply, but also to the State's agricultural industry.

That is why I believe we must take strong action today to curb our greenhouse gas emissions. I hope that this hearing will convince my colleagues of that as well.

Thank you, Mr. Chairman.

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

Senator BINGAMAN. Thank you very much, Mr. Chairman, for having the hearing. This is something which you and I discussed, and I particularly appreciate you doing it at this point, when we are right in the midst of trying to deal with this comprehensive energy bill that we are in a conference with the House about.

I do think this climate change issue, greenhouse gas emissions and climate change, are as significant an issue as we will deal with in the Congress, and I hope very much that this hearing, as you say, will be the beginning of a deliberative process that will lead to a responsible action by us.

I also want to thank the witnesses. We have a very distinguished group of witnesses that have come, some of them from a long way to be here. We very much appreciate their going to the extra trouble of being here. We look forward very much to their testimony. And as you say, I think the purpose, as I see this, is to educate all of us on what is possible, what is needed, what the facts are.

I think this is an issue, like many in our political process, where there is a tendency for us to jump to conclusions and preconceived opinions without really adequately understanding the facts, and hopefully this hearing will help us avoid that in this case. Thank you.

The CHAIRMAN. Thank you very much. Now Senators, we have now quite a number of you here. I would ask you how you think we should proceed. I want you to know that both Senator Bingaman and I have a great number of things to do today, but we can spend most of the morning here. Senator Bingaman cannot.

Senator BINGAMAN. No. I can be here all morning. I just thought that the sooner we get to the witnesses, the better.

The CHAIRMAN. In light of the fact that we cannot go on beyond noon, I would not like to do that, because we cannot be here, I wonder what your pleasure—would you like to make opening statements, any Senators on our side?

Senator MARTINEZ. I would like to put my opening statement on the record.

[The prepared statement of Senator Martinez follows:]

PREPARED STATEMENT OF HON. MEL MARTINEZ, U.S. SENATOR FROM FLORIDA

Chairman Domenici, I want to thank you for your willingness to hold this important hearing today to discuss the economic impacts of climate change strategies and the current state of scientific research in this area. Few issues have a greater impact, or enlist the same type of fervor and passion, as the study of human effects on our global atmosphere. Climate change was a focal point of debate as the Senate debated the Energy Bill and we were presented a host of solutions that many of my colleagues passionately championed to mitigate the impact of releasing greenhouse gases into the air. Today we will hear testimony from a cross-section of our national scientific community. According to the National Academy of Sciences, the mean global surface temperatures have increased by 0.7 degrees since the early 1970s. There is a growing consensus that the Earth is in fact warming.

Serious questions, however, still remain on exactly what course of action we should take. And perhaps more importantly, what are the ramifications of our decisions? What percentage of this global warming trend comes from human activity and from naturally occurring climactic changes? Considering that most energy experts predict phenomenal growth in the use of fossil fuels from India and China, what type of reduction can the U.S. make on emissions of CO_2 that will significantly affect global temperatures? And finally, what will it cost our economy in jobs and lost income to meet global climate objectives? Unfortunately, we do not have finite answers to these critical questions.

There have been some in the science community that have tried to link this warming trend with natural disasters like hurricanes, where four major disasters have battered Florida in the last 10 months. This notion was especially strong after the 2004 hurricane season, when Bonnie, Charley, Frances, and Ivan left a devastating mark on my state that thousands of people are still struggling to recover from their ravages. In a recent issue of the *Bulletin of the American Meteorological Society*, several respected climatologists, researchers, and policymakers from the National Hurricane Center, NOAA's Hurricane Research Division, MIT's Earth, Atmospheric, and Planetary Sciences, and many others found that "no connection has been found between greenhouse gas emissions and the observed behavior of hurricanes." Another respected climatologist from Florida State University, Dr. James O'Brien, has stated that the periodic, oceanic phenomenon of the Atlantic Ocean Conveyor is the real link between hurricane frequency and intensity. He went on to say in an article published in the Orlando Sentinel that "while it is tempting to blame the frequency or intensity of hurricanes on man, we all must remember how variable nature is—and specifically in this case, the effect of natural variations on hurricanes' intensity and frequency is extremely higher than the possibility of man's interference."

Despite the misguided attempts made by some scientists and researchers, we cannot overlook the legitimate, peer-reviewed work of climatologists that are rightly concerned about sea levels, the shrinkage of the polar ice cap, and the impact climate change will have on habitat and threatened animal species. I come from a very environmentally conscious state, where a large majority of my constituents live in coastal areas and are concerned that man-made climate change could potentially threaten the beaches and estuaries that make Florida such a unique and beautiful place.

There is no doubt that we cannot ignore this issue and that is why our President has aggressively pursued record levels of research and development funding to advance our knowledge on the science of climate change. The Bush Administration has committed $6 billion in funding, more than any other nation combined, and has committed to an 18 percent reduction in greenhouse gas intensity from 2002 through 2012; meeting this commitment will prevent the release of 500 million metric tons carbon-equivalent emissions into the air. Most recently, Senators Hagel and Pryor successfully offered an amendment to the Energy Bill that would authorize $2 billion in direct loans, loan guarantees and other incentives for the adoption of technologies that reduce greenhouse gas intensity while directing a federal effort to implement a national climate change strategy. The President and the Senate are acting, but we must continue to push forward.

Again, Mr. Chairman I want to thank you for holding this important hearing today. It is critical that we closely examine the evidence our scientific community is providing us on the status of our atmosphere that help us guide our future actions.

The CHAIRMAN. Any other Senators besides Senator Martinez? Yes, Senator.

Senator MURKOWSKI. Mr. Chairman, I just want to make sure that my opening statement is included as part of the record. As you know, the State of Alaska is kind of the barometer, the bellwether, as we are looking at what is happening right now on the ground as it relates to climate change. I think it is significant, and I would like to make sure that my full comments are included as part of the record.

The CHAIRMAN. Senator, I understand your very grave concern about this matter, and it will be made a part of the record, you are assured.

[The prepared statement of Senator Murkowski follows:]

PREPARED STATEMENT OF HON. LISA MURKOWSKI, U.S. SENATOR FROM ALASKA

I've tried to be brief in the past in my opening statements. I hope that will buy me some leeway today.

Coming from Alaska, which may be the state most affected in the U.S. by future climate change, I have a great deal of interest in this issue.

I start by saying that I have a firm belief that something is going on out there. There is considerable anecdotal and scientific evidence from Alaska that we have been in a prolonged warming cycle for the past three decades.

Last year was the warmest in Alaska in recorded history, with temperatures averaging 5 degrees above normal.

We've seen a general shrinking in glaciers in Alaska, admittedly not in itself proof of global warming.

We've seen the extent of the Arctic ice pack fall by at least a million square kilometers from 1970 to 2000, according to at least five studies. And we've seen the thickness of the pack ice thin.

We've seen permafrost, the frozen soil mixture that underlies much of northern Alaska, warm threatening the foundation of roads, buildings and even pipelines.

Earlier this summer scientists at the University of Alaska found that lakes in Siberia, and more importantly to me near the Tanana Flats and on the Kenai Peninsula in Alaska and in the Yukon Territory, are dropping in size and number because thawing permafrost apparently is allowing water to seep out.

These changes have resulted in a host of biological impacts:

- Perhaps a decline in Alaskan king crab stocks that like cold water;
- An increase in spruce bark beetle infestations that have claimed more than 6 million acres of Alaska spruce since the beetles survive better in warmer winters;
- We've seen birds move to more northern nesting zones;
- And we've had reports from Native North Slope villagers that subsistence harvests are becoming more difficult for everything from polar bears and walrus to whales, because of the shrinking pack ice.

The warming temperatures and receding of the pack ice is intensifying the effects of winter storms, increasing coastal erosion. On the North Slope of Alaska in the National Petroleum Reserve there is a wonderful area for waterfowl nesting north of Teshekpuk Lake. Some worry the area may be harmed by future oil development. But the far bigger concern is that coastal erosion will devastate and inundate this prized breeding, nesting and molting area for waterfowl.

The Intergovernmental Panel on Climate Change last year projected that average global surface temperatures will continue to rise by between 1.4 and 5.8 degrees centigrade above 1990 levels by the end of this century. Some models indicate that could translate into a far higher temperature hike in the high Arctic, especially in winter.

But then we hear from University of Alaska researchers that Arctic/Beaufort Sea temperatures actually fell last summer for the first time in 29 years.

The science on why the climate has been warming is far from conclusive.

How much is simply cyclic?

How much is man-induced?

Is it largely driven by the increase in greenhouse gases?

How much of that rise can we realistically arrest given a growing global population?

1) Clearly we have seen similar or higher increases in temperatures in the Arctic, and across the planet, at least on four other occasions during the past 400,000 years—and none of the previous temperature changes were caused by man.

2) Climate trends certainly look very different, depending upon the time scale that is being considered. So much of the fear over climate is based on data from just the past 100 years—a period when admittedly carbon dioxide levels have risen, from 280 parts per million before the industrial revolution to more than 375 ppm today. But what is the evidence, compared to supposition and theory, that that rise is truly what is fueling current climate conditions?

3) While the Arctic Climate Impact Assessment, sponsored by the Arctic Council, last year suggested that greenhouse gases are triggering climate change, there is credible evidence that, as George Taylor, a climatologist at Oregon State University says, a cyclic increase in solar radiation and/or the changes in the North Atlantic or Pacific Decadal Oscillations that affect currents and thus sea surface air temperatures and ice thicknesses, may really be what's at work.

I am certainly willing to start this debate by acknowledging climate change, but I still need have not seen the conclusive evidence that carbon emissions are the sole cause of climate change.

However I am willing to take steps NOW to reduce greenhouse gas releases, as a prudent measure—recognizing that we don't want to devastate our economy, harming our ability to pay for environmental protection.

That is why in the Senate energy bill I co-sponsored an effort by Senator Hagel to spend up to $4 billion to develop technology to sequester carbon and reduce its discharge into the atmosphere.

That is one reason why I've been pushing in the energy bill for tax breaks for pumping CO_2 underground to enhance oil recovery. We keep the carbon out of the atmosphere and increase the production of our domestic oil by enhanced oil recovery—a true "win-win" situation for the nation, especially if we can capture up to another 42 billion barrels of oil in the process.

For all these reasons I truly am interested in understanding the impacts of Sen. Bingaman's proposal, patterned after the National Commission on Energy Policy.

Last month there wasn't enough time to fully understand the huge implications of the concept, how it would affect the economy, foreign output of CO_2, the competitiveness of not just our energy sector but of all industries in America. How the initial credits can be equitably distributed, how the price for future emission credits may affect the economy, whether the safety value price—$7 per ton—is so low compared to European costs that the system really is meaningless, or whether it will become so high that it will have the negative impacts that many in industry have complained about.

In a perfect world I might want to give the President's February 2002 voluntary initiative to reduce greenhouse gas intensity more time to work. (He proposed that we cut greenhouse gas intensity by 18 percent by 2012. A level that would emit 500 million metric tons less carbon to the atmosphere—a responsible goal.)

But I am open to evidence, that prudence directs us to do more now to reduce greenhouse gas emissions. I have much more I could say about the cap and trade concept, but for this hearing I'll simply listen and learn and perhaps speak directly to the proposal during a second round of questions or at a future hearing.

Thank you Mr. Chairman for your indulgence.

Senator AKAKA. Mr. Chairman?

The CHAIRMAN. Yes, Senator.

Senator AKAKA. Mr. Chairman, thank you for holding this hearing. I appreciate the consistent attention that this committee has given the issue of climate science and adaptation to global climate change. In the interest of time, Mr. Chairman, I will submit my full statement for the record.

The CHAIRMAN. Thank you very much.

[The prepared statement of Senator Akaka follows:]

PREPARED STATEMENT OF HON. DANIEL K. AKAKA, U.S. SENATOR FROM HAWAII

Thank you, Mr. Chairman, for scheduling this hearing on climate change and the economics of carbon dioxide controls. I appreciate the consistent attention that this committee has given to the issue of climate science and adaptation to global climate change. Since I joined the committee over 10 years ago, we have held a hearing *nearly every year* on the general topic.

There is no denying that carbon dioxide in the atmosphere has reached higher levels than at any time in the history of the earth. We are implicated—as human beings and as a nation—for our role in contributing to the buildup. The burning of fossil fuels has accelerated the situation for the last hundred years and the U.S. contributes more carbon dioxide to the atmosphere than any other nation.

I am particularly concerned for islands in the Pacific. There are changes in our islands in Hawaii that can only be explained by global phenomena such as the buildup of carbon dioxide. Globally, sea level has increased 6 to 14 inches in the last century and it is likely to rise another 17 to 25 inches by 2100. This would be a one- to two-foot rise. You can imagine what this might mean to port operators, shoreline property owners, tourists and residents who use Hawaii's beautiful beaches, and to island nations and territories in the Pacific whose highest elevation is between 3 and 100 meters above sea level. A typhoon or hurricane would be devastating to communities on these islands, not to mention the low-lying coastal wetlands of the continental United States.

There is an important, but usually overlooked, issue of environmental *injustice* to climate change and sea level rise. In particular, small island states in the Caribbean, such as Nevis, the Cayman Islands, and Bonaire; in the Pacific, islands of Vanuatu and the Marshall Islands; or in the Indian Ocean, the Maldives, will bear the brunt of climate change in the future, even though they account for less than one percent of the greenhouse gas emissions that are driving climate changes.

I have talked about my concerns regarding climate change on the floor and in this committee. I have urged the U.S. to be a leader in addressing climate change and carbon emissions. We seem to be mired in *inaction*—even though the Senate adopted a resolution affirming the reality of climate change in the Senate's energy bill, H.R. 6. I have said in the past that we must not get *stuck* in estimating the *costs* of implementing carbon controls. Inaction may not mean much if you are high and dry in the nation's Capitol, 90 miles from the Atlantic Ocean. But if you are surrounded by water, the risk of inaction is very real, and very frightening.

We need a different plan of action instead of focusing on the relative costs of carbon containment strategies. I propose that we embrace the just-passed Senate resolution—meaning that we embrace the reality of carbon dioxide accumulation—and also embrace the opportunity to use mandatory controls as a way to grow our economy.

There is no doubt that the engineering communities, think tanks, universities, Wall Street and the commodity traders, and industry can pull together to made this an *opportunity* rather than a bleak picture of increased regulation and job loss. This can be a *national enterprise*, a mobilization to contain carbon growth. I would like to see a national Commission that would focus on the job *growth* and technology investment needed to limit or reduce greenhouse gases, and the steps needed for a strategy to get there. If we embrace this issue as a nation, I am convinced that our human resources, technological and scientific expertise, and "national will" can beat it and the U.S. can act as a leader for the rest of the world in reducing carbon emissions.

Mr. Chairman, I look forward to hearing the testimony of the distinguished witnesses today, and I have some questions for them.

The CHAIRMAN. Yes, Senator Cantwell?

Senator CANTWELL. Mr. Chairman, I also submit my statement for the record.

[The prepared statement of Senator Cantwell follows:]

PREPARED STATEMENT OF HON. MARIA CANTWELL, U.S. SENATOR FROM WASHINGTON

Mr. Chairman, thank you for holding this incredibly important hearing.

I apologize for not being to be here earlier, I had to attend a concurrent Commerce Committee markup.

First I would like to commend Senator Bingaman for his leadership on this issue, and his ongoing efforts to develop a bipartisan legislative solution to finally begin addressing the enormous challenge global warming poses our nation and our planet. And I want to thank the Chairman again for agreeing to undertake this hearings process.

Like many of my colleagues, and most Americans, I have grown increasingly frustrated that, despite overwhelming scientific consensus that climate change is real and its consequences will be incredibly harmful to our economy, Congress and the President have failed to seriously tackle this issue.

I was disappointed that we passed a thousand page energy bill out of the Senate, but took a pass on dealing directly with one of the central energy challenges of our time, the threat of global warming.

But today is essentially a new beginning to this debate—in part, thanks to the fact that the Senate did unanimously adopt a resolution committing us to develop a mandatory, national, market-based program to limit greenhouse gas accumulations. While this is a complex challenge, we have many of our brightest minds considering how to best structure such a program. Some of those individuals are testifying before us today, and I thank them for their work.

We can also learn from the example of our international allies, many of which have enacted comprehensive programs to begin addressing this worldwide threat. In addition, 28 states and many cities have developed detailed climate change action plans and other initiatives to lower future greenhouse gas emissions.

I am proud that Washington state is one of those states taking the lead. And we have good reason to do so. As a number of my colleagues on this Committee are aware, the Pacific Northwest is a region totally unique in the way our energy system is structured. Our river—the great Columbia River and its tributaries—is the lifeblood of our economy. It produces 80 percent of Washington state's electricity. But it is also the engine of our fishing and farming industries, home to our region's salmon runs, and impacts almost every sector of our economy including navigation and recreation.

Given the low emissions-intensity of our energy system, it is a bitter irony that one of the primary impacts of global warming in the Pacific Northwest may be to change our rainfall patterns in a way that could shift the dynamics of our great river and power system. The Columbia is fed by snowpack, and as a testament to the international aspects of this debate, its headwaters are located north of our border, in British Columbia's Selkirk Mountains. Some scientists, like those at the University of Washington's Climate Impacts Group, believe that global warming may dramatically impact Northwest snowpack by as much as 35 percent in the next 50 years—compared to the historical averages for 1950 to 1999.

The Columbia is a river of multiple uses, and as our region has grown the balancing act has become more difficult. Nevertheless, it is a balance that can be achieved. I am very concerned, however, about the threat posed to our system by climate change. A significant and prolonged shift in our region's precipitation patterns would not only harm electricity generation, it would also impact billions of dollars of economic infrastructure associated with irrigation systems, municipal water supplies, even ski resorts that depend on our historic snowfall patterns.

I know the Chairman said at the outset that there would be additional hearings on this matter, and I do hope that climate adaptation issues—particularly in the Northwest—might be an additional focus. As we attempt to weigh the right legislative approach to global warming and the costs of tackling the challenge, we must also take a holistic view of those costs. The global warming trend, left unmitigated, could severely damage the economy of a region like mine, where the health of our river—not to mention the health of our marine ecosystems—are completely intertwined with the fate of many of our most important industries.

Again, my state's dynamic highlights the fact that it doesn't matter where the heat-trapping gases originate, they have an impact all over the world.

This point was made clear to me when I visited a global atmosphere monitoring station on the very southern tip of the African continent. Overlooking the vast ocean toward Antarctica, this little station on a cliff is able to detect the greenhouse gas emissions generated from all over the Northern Hemisphere and provide data to help calculate the warming they are causing.

Mr. Chairman, our nation is responsible for a full quarter of the burden climate change will cause our world. We are potentially talking about billions, if not trillions, of dollars in cumulative economic dislocation, and risking millions of lives in the developing world due to increased extreme weather events, shifts in disease patterns, and failure of subsistence farming.

That's why I believe we must act and put in place a comprehensive program to begin reversing this threat as soon as possible.

We are a problem-solving nation. When we are faced with a grave threat, we roll up our sleeves, put our heads together, and fix our problems; we don't push them off on our children and future generations.

Again, thank you for holding this important hearing.

Senator CANTWELL. And if I could inquire if it's your intention to then vote on the action of the hearing at the time that we receive a quorum?

The CHAIRMAN. The five nominees?

Senator CANTWELL. Yes.

The CHAIRMAN. Absolutely. But they have to be present all at one time. So if people leave, that is not going to count. We have to have 12 present. And then they are already before the Senate. I have just made them part of the Senate. We have had hearings. The hearings are closed. We have noted no objection heretofore, so that is how we will proceed, Senator.

Senator CANTWELL. Okay.

The CHAIRMAN. Senator Salazar.

Senator SALAZAR. Mr. Chairman, thank you, and thanks, Senator Bingaman, for this important hearing. And I, too, will have a statement for the record. Thank you.

The CHAIRMAN. All right.

[The prepared statement of Senator Salazar follows:]

PREPARED STATEMENT OF HON. KEN SALAZAR, U.S. SENATOR FROM COLORADO

Thank you, Mr. Chairman. I'd like to thank you and Senator Bingaman for your desire to work together in the search for effective climate change legislation—legislation that will move America in the right direction by reducing our greenhouse gas emissions.

The issue at hand is an important one. We need to address the problem of climate change and greenhouse gas emissions, and the problem is growing more urgent every year. We need to find a solution that, as stated in the Sense of the Senate Resolution passed earlier this year, "will not significantly harm the United States Economy." I am certain that an economically modest strategy is possible.

The Senate version of the energy bill, currently in conference, makes some steps forward, by slowly but significantly increasing our production of renewable fuels and renewable energy. As the Chairman as already indicated, the Senate Energy bill also includes some important incentives designed to reduce greenhouse gas emissions by encouraging the development of new, clean energy technologies. I sincerely hope these excellent provisions will remain in the energy bill. These provisions will serve America well, reducing our greenhouse gas emissions while strengthening our energy security.

But these provisions will not be enough, and that is why meaningful climate change legislation is needed. I am looking forward to a rational, and factual, discussion of the problem at hand. In particular, the economic panel will address concerns regarding the cost of climate change legislation and its potential effect on various industries. There are naysayers, who loudly state that any type of climate change legislation would be devastating on our economy, but those individuals are misinformed. I believe industries important to Colorado and to America—such as coal—will continue to thrive under good climate change legislation, and I look forward to examining that further in our discussion here today.

The CHAIRMAN. We are ready. Then any other Senators that arrive—Senator Talent, the issue is: Do you want to make a statement or put one in the record?

Senator TALENT. In the record would be fine, Mr. Chairman.

The CHAIRMAN. All right. We will do that, Senator.

[The prepared statement of Senator Talent follows:]

PREPARED STATEMENT OF HON. JAMES M. TALENT, U.S. SENATOR FROM MISSOURI

I thank the Chairman and Ranking Member for tackling this very difficult issue.

Like so many of the issues we seem to be facing recently, climate change is one where the stakes are high on both sides, a lot of money and forecasting is involved, and there is considerable disagreement over the degree of the problem and the likely outcome after all of the money is spent.

I know a lot of bright minds have spent considerable amounts of time and effort studying climate change and, while we've been at this a while, the science is relatively new and still has a ways to go to produce the kinds of answers we'd all like to have.

Nevertheless, I expect that what we'll hear today is that there's a broad-based consensus that,

1. over the last 100 or so years, the temperature of the Earth has risen;
2. over that same period, the concentration of greenhouse gases such as carbon dioxide has also risen;
3. because of this correlation, there is evidence that at least some of the temperature rise is attributable to the burning of fossil fuels; and
4. man, therefore, has some level of ability to mitigate the warming of the Earth through controlling greenhouse gas emissions.

I don't necessarily disagree with these conclusions, though what troubles me is the uncertainty that remains with respect to several key factors underlying any conclusions on climate change, namely

1. to what degree is the current warming due to the numerous natural, cyclical changes, some of which are measured over hundreds or thousands of years;
2. to what degree is the current warming due to the burning of fossil fuels;
3. how sensitive is the climate to changes in greenhouse gas concentration; and
4. how accurate are the models and the data inputs.

I am curious as to whether, as the science advances, we find that predictions of excessive temperature increases are in fact overstated.

In either case, the presence of a fair bit of uncertainty as to what will in fact happen 50, 75, or 100 years from now, coupled with the global nature of this issue and its economic ramifications, makes it much more difficult to heed calls for immediate action on climate change. This is particularly true since it is apparent to most that the technology needed to make an appreciable dent in global emissions is not yet available.

What worries me the most are calls for partial solutions to problems that are not fully defined. For example, one outcome of this debate could be that the United States invests billions of dollars to reduce emissions; this cost drives industry and jobs overseas, harming our economy while not making any improvement in greenhouse gas concentrations, as developing countries like China and India replace the manufacturing formerly done in the U.S. without, of course, any effort to cut emissions.

If this scenario plays out, we end up losing three times—energy costs go up, jobs disappear, and global emissions are not reduced at all. This would be particularly painful if we push for this kind of change prior to the technology being in place to make it possible without draconian cuts in fossil fuel use, particularly coal.

In all of this, I am not yet convinced whether we will see any tangible benefits for the large sums of money that are at stake here. I understand that there is a time when you must make a decision based on the best available information. But usually you have some degree of certainty that the chosen option will work, or at least that you know its true cost. In this case, I am concerned that there is a great deal of uncertainty with respect to both the likelihood of success and the cost to achieve it.

Some view the Kyoto Protocol, which is much more demanding than the Bingaman proposal, as just the beginning, meaning even greater emissions cuts must be made. I wonder if anyone has done the math on the cost for going the whole nine yards and cutting emissions to the level some say we must get to. I think people are afraid of putting that number in print.

Nevertheless, our energy bill contains a number of incentives for voluntarily adopting technology to control emissions both here and abroad. I'm in favor of this approach because it's working already.

In addition, it's the only way we can bring developing countries like China and India on board.

The electric industry has taken a number of steps to meet the Administration's target. Edison Electric Institute's members have committed to voluntarily reduce

GHG emissions intensity by 3-5 percent in the next decade. Other sectors of the economy made similar commitments in order to help meet the President's goal of 18 percent. Specifically, in the last 10 years, they have reduced, avoided, or sequestered 7 million tons of carbon dioxide system wide and are committed to doing more. Plus, several utilities, including utilities in my state, are planning to build new coal fired generators using the latest proven clean coal technology.

I hope as we go forward we will be able to find solutions that recognize that economic growth and prosperity are the best means of achieving environmental protection.

The CHAIRMAN. Can we have panel number one come to the table? Dr. Ralph Cicerone, Dr. Mario Molina, Dr. Jim Hurrell, Sir John Houghton. Could you tell me your name again, Doctor? Say it for me.

Sir HOUGHTON. Houghton.

The CHAIRMAN. Houghton.

Sir HOUGHTON. Correct.

The CHAIRMAN. I will never get it right, but pretty close. Now I do not have to tell everybody who you are. I would not have to. But I think it is important that we just quickly state it.

Dr. Ralph Cicerone is president of the National Academy of Sciences and chairman of the National Research Council. Dr. Mario Molina is a professor of Earth, Atmospheric and Planetary Sciences at the Massachusetts Institute of Technology. Dr. Hurrell is a scientist with Science Climate and Global Dynamics. And then our friend from England, Sir Houghton, is co-chairman of the Scientific Assessment Workshop, Intergovernmental Panel on Climate Change.

Now we are going to proceed in the order which I called your names, if you will. We are very interested in what you have to say. On the other hand, we want everybody on this panel to have an opportunity to inquire. So with that, would you keep your statements as brief as possible.

Right now, we will inform each of you that whatever statement you have brought to us will be made a part of the record. Having said that, if you can abbreviate, fine. If you cannot, we expect to let you tell us exactly what you want. And how you want to say it is up to you. Please proceed. We will go with you first, Doctor.

Dr. CICERONE. Oh. Okay.

The CHAIRMAN. In the order that I called the names.

STATEMENT OF RALPH J. CICERONE, PH.D., PRESIDENT, NATIONAL ACADEMY OF SCIENCES

Dr. CICERONE. Thank you, Senator Domenici. My name is Ralph Cicerone. I am president of the National Academy of Sciences, as of about 3 weeks ago. I certainly appreciate the opportunity to be here. There is no question that energy, energy technology, energy usage patterns are very central to implications of climate change. So your attention is certainly necessary and highly desirable from everybody's point of view.

This morning I would like to summarize briefly the current state of scientific understanding on climate change, based largely on findings and recommendations in recent National Academies reports. These reports are the products of study processes that bring together leading scientists, engineers, public health officials, and other experts to provide consensus readings and advice to the Nation on specific scientific and technical questions.

The earth is warming. Weather station records and ship-based observations for about the last 130, 140 years indicate that global mean surface air temperature increased, just since the 1970's, about 7⁄10 of a degree Fahrenheit. In my written testimony, which you were kind enough to include, I have a figure of such data, a graph.

The magnitude of the warming does vary locally and from region to region. However, the warming trend is spatially widespread, planetary, and it is consistent with an array of other evidence, including melting glaciers and ice caps, sea-level rise, extended growing seasons, and changes in geographical distributions of plant and animal species.

The ocean, which represents, because of the heat capacity of water, the largest reservoir of heat in the climate system, has itself warmed by about .12 degrees Fahrenheit, average down to 750 feet depth just in the last 12 years. And recent studies have shown that the observed heat storage in the ocean is consistent with the expected impacts of the human-enhanced greenhouse effect.

The observed warming, however, has not proceeded at a uniform rate. For example, there was a bit of a cooling, especially in the northern hemisphere from 1940 to 1975, warming until 1940, and then a much more rapid warming since the late 1970's.

Laboratory measurements of gases that have been extracted from dated ice cores have shown that for the last hundreds of thousands of years changes in temperature have closely tracked atmospheric carbon dioxide amounts, and that carbon dioxide in the atmosphere is now at its highest level in 400,000 years, as it continues to rise.

Nearly all climate scientists today believe that much of the earth's current warming has been caused by increases in these greenhouse gases in the atmosphere, mostly from the burning of fossil fuels. And the degree of confidence in this conclusion is higher today than it was 10 years ago or even 5 years ago, and yet, uncertainties do remain.

As stated in our 2001 National Academy of Sciences report, 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 also reflects natural variability.

An example of an area of debate of a natural cause of this warming has involved a question of whether or not the sun itself has brightened. Fortunately, in the last 25 years or so, humans have measured the output of the sun carefully enough, with enough precision, to shed some light on the question. And although there are still uncertainties due to stringing together records from different instruments and different satellites, the most empirical reading of the record, I believe, shows that the sun's output has not changed. There has been no trend, aside from the 11-year cycles which were previously known. And, therefore, it is much more difficult to say today that the sun's brightening has been the cause of the warming. It does not command much credence.

As you know, carbon dioxide can remain in the atmosphere for many decades, and some part of the climate system respond slowly to these changes, so that we can predict confidently that this warming will continue even though other forces are at play. And the emissions to be—for the concentrations in the atmosphere to be stabilized would require a long-term attack on emissions.

The simulations of future climate change, which I hope that other witnesses speak about more, are that global surface temperatures will continue to rise, and that in the coming century, the present century, the rises could be from 2½ to about 10 degrees Fahrenheit above 1990 temperatures.

This range reflects not only uncertainties as to details of the climate system, but also uncertainties in future human behavior. How many people will there be? What will our energy consumption patterns be? And what will our sources of energy be?

We have discussed in many of our reports remaining scientific uncertainties, what kinds of research are needed. One of the most telling is having to do with regional and local climate changes, where prediction is much more difficult, and yet it is where people want to know what will happen very clearly.

The possible changes and the frequency of severe events like droughts and temperature extremes and water needs and electrical needs that flow from those extreme events represent some of the most difficult to predict phenomena.

In my written testimony I go on and summarize more of the current state of scientific understanding, and give a lot of references. With your permission I will stop here and be available to answer any questions that I may. Thank you, Senator Domenici.

The CHAIRMAN. Thank you very much.

[The prepared statement of Dr. Cicerone follows:]

PREPARED STATEMENT OF RALPH J. CICERONE, PH.D., PRESIDENT, NATIONAL ACADEMY OF SCIENCES

Good morning, Mr. Chairman and members of the Committee. My name is Ralph Cicerone, and I am President of the National Academy of Sciences. Prior to this position, I served as Chancellor of the University of California at Irvine, where I also held the Daniel G. Aldrich Chair in Earth System Science. In addition, in 2001 I chaired the National Academies committee that wrote the report, *Climate Change Science: An Analysis of Some Key Questions*, at the request of the White House.

This morning I will summarize briefly the current state of scientific understanding on climate change, based largely on the findings and recommendations in recent National Academies' reports. These reports are the products of a study process that brings together leading scientists, engineers, public health officials and other experts to provide consensus advice to the nation on specific scientific and technical questions.

The Earth is warming. Weather station records and ship-based observations indicate that global mean surface air temperature increased about 0.7° F (0.4° C) since the early 1970's (See Figure*). Although the magnitude of warming varies locally, the warming trend is spatially widespread and is consistent with an array of other evidence (including melting glaciers and ice caps, sea level rise, extended growing seasons, and changes in the geographical distributions of plant and animal species). The ocean, which represents the largest reservoir of heat in the climate system, has warmed by about 0.12° F (0.06° C) averaged over the layer extending from the surface down to 750 feet, since 1993. Recent studies have shown that the observed heat storage in the oceans is consistent with expected impacts of a human-enhanced greenhouse effect.

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 from the 1970s until today, with a slight cooling of the Northern Hemisphere during the interim decades. The causes of these irregularities and the disparities in the timing are not completely understood, but the warming

*The figure has been retained in committee files.

trend in global-average surface temperature observations during the past 30 years is undoubtedly real and is substantially greater than the average rate of warming during the 20th century.

Laboratory measurements of gases trapped in dated ice cores have shown that for hundreds of thousands of years, changes in temperature have closely tracked atmospheric carbon dioxide concentrations. Burning fossil fuel for energy, industrial processes, and transportation releases carbon dioxide to the atmosphere. Carbon dioxide in the atmosphere is now at its highest level in 400,000 years and continues to rise.

Nearly all climate scientists today believe that much of Earth's current warming has been caused by increases in the amount of greenhouse gases in the atmosphere, mostly from the burning of fossil fuels. The degree of confidence in this conclusion is higher today than it was 10, or even 5 years ago, but uncertainties remain. As stated in the Academies 2001 report, "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."

One area of debate has been the extent to which variations in the Sun might contribute to recent observed warming trends. The Sun's total brightness has been measured by a series of satellite-based instruments for more than two complete 11-year solar cycles. Recent analyses of these measurements argue against any detectable long-term trend in the observed brightness to date. Thus, it is difficult to conclude that the Sun has been responsible for the warming observed over the past 25 years.

Carbon dioxide can remain in the atmosphere for many decades and major parts of the climate system respond slowly to changes in greenhouse gas concentrations. The slow response of the climate system to increasing greenhouse gases also means that changes and impacts will continue during the 21st century and beyond, even if emissions were to be stabilized or reduced in the near future.

Simulations of future climate change project that, by 2100, global surface temperatures will be from 2.5 to 10.4° F (1.4 to 5.8° C) above 1990 levels. Similar projections of temperature increases, based on rough calculations and nascent theory, were made in the Academies first report on climate change published in the late 1970s. Since then, significant advances in our knowledge of the climate system and our ability to model and observe it have yielded consistent estimates. Pinpointing the magnitude of future warming is hindered both by remaining gaps in understanding the science and by the fact that it is difficult to predict society's future actions, particularly in the areas of population growth, economic growth, and energy use practices.

Other scientific uncertainties about future climate change relate to the regional effects of climate change and how climate change will affect the frequency and severity of weather events. Although scientists are starting to forecast regional weather impacts, the level of confidence is less than it is for global climate projections. In general, temperature is easier to predict than changes such as rainfall, storm patterns, and ecosystem impacts.

It is important to recognize however, that while future climate change and its impacts are inherently uncertain, they are far from unknown. The combined effects of ice melting and sea water expansion from ocean warming will likely cause the global average sea-level to rise by between 0.1 and 0.9 meters between 1990 and 2100. In colder climates, such warming could bring longer growing seasons and less severe winters. Those in coastal communities, many in developing nations, will experience increased flooding due to sea level rise and are likely to experience more severe storms and surges. In the Arctic regions, where temperatures have risen more than the global average, the landscape and ecosystems are being altered rapidly.

The task of mitigating and preparing for the impacts of climate change will require worldwide collaborative inputs from a wide range of experts, including natural scientists, engineers, social scientists, medical scientists, those in government at all levels, business leaders and economists. Although the scientific understanding of climate change has advanced significantly in the last several decades, there are still many unanswered questions. Society faces increasing pressure to decide how best to respond to climate change and associated global changes, and applied research in direct support of decision making is needed.

My written testimony describes the current state of scientific understanding of climate change in more detail, based largely on important findings and recommendations from a number of recent National Academies' reports.

THE EARTH IS WARMING

The most striking evidence of a global warming trend are closely scrutinized data that show a relatively rapid increase in temperature, particularly over the past 30 years. Weather station records and ship-based observations indicate that global mean surface air temperature increased about 0.7° F (0.4° C) since the early 1970's. Although the magnitude of warming varies locally, the warming trend is spatially widespread and is consistent with an array of other evidence (e.g., melting glaciers and ice caps, sea level rise, extended growing seasons, and changes in the geographical distributions of plant and animal species).

The ocean, which represents the largest reservoir of heat in the climate system, has warmed by about 0.12° F (0.06° C) averaged over the layer extending from the surface down to 750 feet, since 1993. Recent studies have shown that the observed heat storage in the oceans is what would be expected by a human-enhanced greenhouse effect. Indeed, increased ocean heat content accounts for most of the planetary energy imbalance (i.e., when the Earth absorbs more energy from the Sun than it emits back to space) simulated by climate models with mid-range climate sensitivity.

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 since the 1970s, with a slight cooling of the Northern Hemisphere during the interim 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.

A National Academies report released in 2000, *Reconciling Observations of Global Temperature Change*, examined different types of temperature measurements collected from 1979 to 1999 and concluded that the warming trend in global-average surface temperature observations during the previous 20 years is undoubtedly real and is substantially greater than the average rate of warming during the 20th century. The report concludes that the lower atmosphere 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 report spurred many research groups to do similar analyses. Satellite observations of middle troposphere temperatures, after several revisions of the data, now compare reasonably with observations from surface stations and radiosondes, although some uncertainties remain.

HUMANS HAVE HAD AN IMPACT ON CLIMATE

Laboratory measurements of gases trapped in dated ice cores have shown that for hundreds of thousands of years, changes in temperature have closely tracked with atmospheric carbon dioxide concentrations. Burning fossil fuel for energy, industrial processes, and transportation releases carbon dioxide to the atmosphere. Carbon dioxide in the atmosphere is now at its highest level in 400,000 years and continues to rise. Nearly all climate scientists today believe that much of Earth's current warming has been caused by increases in the amount of greenhouse gases in the atmosphere. The degree of confidence in this conclusion is higher today than it was 10, or even 5 years ago, but uncertainties remain. As stated in the Academies 2001 report, "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."

Carbon dioxide can remain in the atmosphere for many decades and major parts of the climate system respond slowly to changes in greenhouse gas concentrations. The slow response of the climate system to increasing greenhouse gases also means that changes and impacts will continue during the 21st century and beyond, even if emissions were to be stabilized or reduced in the near future.

In order to compare the contributions of the various agents that affect surface temperature, scientists have devised the concept of "radiative forcing." Radiative forcing is the change in the balance between radiation (i.e., heat and energy) entering the atmosphere and radiation going back out. Positive radiative forcings (e.g., due to excess greenhouse gases) tend on average to warm the Earth, and negative radiative forcings (e.g., due to volcanic eruptions and many human-produced aerosols) on average tend to cool the Earth. The Academies' recent report, *Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties* (2005), takes a close look at how climate has been changed by a range of forcings. A key message from the report is that it is important to quantify how human and natural processes cause changes in climate variables other than temperature. For example, climate-driven changes in precipitation in certain regions could have significant impacts on water availability for agriculture, residential and industrial use, and recreation. Such regional impacts will be much more noticeable than projected changes in global average temperature of a degree or more.

One area of debate has been the extent to which variations in the Sun might contribute to recent observed warming trends. *Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties* (2005) also summarizes current understanding about this issue. The Sun's brightness—its total irradiance—has been measured continuously by a series of satellite-based instruments for more than two complete 11-year solar cycles. These multiple solar irradiance datasets have been combined into a composite time series of daily total solar irradiance from 1979 to the present. Different assumptions about radiometer performance lead to different reconstructions for the past two decades. Recent analyses of these measurements, taking into account instrument calibration offsets and drifts, argue against any detectable long-term trend in the observed irradiance to date. Likewise, models of total solar irradiance variability that account for the influences of solar activity features—dark sunspots and bright faculae—do not predict a secular change in the past two decades. Thus, it is difficult to conclude from either measurements or models that the Sun has been responsible for the warming observed over the past 25 years.

Knowledge of solar irradiance variations is rudimentary prior to the commencement of continuous space-based irradiance observations in 1979. Models of sunspot and facular influences developed from the contemporary database have been used to extrapolate daily variations during the 11-year cycle back to about 1950 using contemporary sunspot and facular proxies, and with less certainty annually to 1610. Circumstantial evidence from cosmogenic isotope proxies of solar activity (^{14}C and ^{10}Be) and plausible variations in Sun-like stars motivated an assumption of long-term secular irradiance trends, but recent work questions the evidence from both. Very recent studies of the long term evolution and transport of activity features using solar models suggest that secular solar irradiance variations may be limited in amplitude to about half the amplitude of the 11-year cycle.

WARMING WILL CONTINUE, BUT ITS IMPACTS ARE DIFFICULT TO PROJECT

The Intergovernmental Panel on Climate Change (IPCC), which involves hundreds of scientists in assessing the state of climate change science, has estimated that, by 2100, global surface temperatures will be from 2.5 to 10.4° F (1.4 to 5.8° C) above 1990 levels. Similar projections of temperature increases, based on rough calculations and nascent theory, were made in the Academies first report on climate change published in the late 1970s. Since then, significant advances in our knowledge of the climate system and our ability to model and observe it have yielded consistent estimates. Pinpointing the magnitude of future warming is hindered both by remaining gaps in understanding the science and by the fact that it is difficult to predict society's future actions, particularly in the areas of population growth, economic growth, and energy use practices.

One of the major scientific uncertainties is how climate could be affected by what are known as "climate feedbacks." Feedbacks can either amplify or dampen the climate response to an initial radiative forcing. During a feedback process, a change in one variable, such as carbon dioxide concentration, causes a change in temperature, which then causes a change in a third variable, such as water vapor, which in turn causes a further change in temperature. *Understanding Climate Change Feedbacks* (2003) looks at what is known and not known about climate change feedbacks and identifies important research avenues for improving our understanding.

Other scientific uncertainties relate to the regional effects of climate change and how climate change will affect the frequency and severity of weather events. Although scientists are starting to forecast regional weather impacts, the level of confidence is less than it is for global climate projections. In general, temperature is easier to predict than changes such as rainfall, storm patterns, and ecosystem impacts. It is very likely that increasing global temperatures will lead to higher maximum temperatures and fewer cold days over most land areas. Some scientists believe that heat waves such as those experienced in Chicago and central Europe in recent years will continue and possibly worsen. The larger and faster the changes in climate, the more difficult it will be for human and natural systems to adapt without adverse effects.

There is evidence that the climate has sometimes changed abruptly in the past—within a decade—and could do so again. Abrupt changes, for example the Dust Bowl drought of the 1930's displaced hundreds of thousands of people in the American Great Plains, take place so rapidly that humans and ecosystems have difficulty adapting to it. *Abrupt Climate Change: Inevitable Surprises* (2002) outlines some of the evidence for and theories of abrupt change. One theory is that melting ice caps could "freshen" the water in the North Atlantic, shutting down the natural ocean circulation that brings warmer Gulf Stream waters to the north and cooler waters south again. This shutdown could make it much cooler in Northern Europe and warmer near the equator.

It is important to recognize that while future climate change and its impacts are inherently uncertain, they are far from unknown. The combined effects of ice melting and sea water expansion from ocean warming will likely cause the global average sea-level to rise by between 0.1 and 0.9 meters between 1990 and 2100. In colder climates, such warming could bring longer growing seasons and less severe winters. Those in coastal communities, many in developing nations, will experience increased flooding due to sea level rise and are likely to experience more severe storms and surges. In the Arctic regions, where temperatures have risen almost twice as much as the global average, the landscape and ecosystems are being altered rapidly.

OBSERVATIONS AND DATA ARE THE FOUNDATION OF CLIMATE CHANGE SCIENCE

There is nothing more valuable to scientists than the measurements and observations required to confirm or contradict hypotheses. In climate sciences, there is a peculiar relation between the scientist and the data. Whereas other scientific disciplines can run multiple, controlled experiments, climate scientists must rely on the one realization that nature provides. Climate change research requires observations of numerous characteristics of the Earth system over long periods of time on a global basis. Climate scientists must rely on data collected by a whole suite of observing systems—from satellites to surface stations to ocean buoys—operated by various government agencies and countries as well as climate records from ice cores, tree rings, corals, and sediments that help reconstruct past change.

COLLECTING AND ARCHIVING DATA TO MEET THE UNIQUE NEEDS OF CLIMATE CHANGE SCIENCE

Most of the instrumentation and observing systems used to monitor climate today were established to provide data for other purposes, such as predicting daily weather; advising farmers; warning of hurricanes, tornadoes and floods; managing water resources; aiding ocean and air transportation; and understanding the ocean. However, collecting climate data is unique because higher precision is often needed in order to detect climate trends, the observing programs need to be sustained indefinitely and accommodate changes in observing technology, and observations are needed at both global scales and at local scales to serve a range of climate information users.

Every report on climate change produced by the National Academies in recent years has recommended improvements to climate observing capabilities. A central theme of the report *Adequacy of Climate Observing Systems* (1999) is the need to dramatically upgrade our climate observing capabilities. The report presents ten climate monitoring principles that continue to be the basis for designing climate observing systems, including management of network change, careful calibration, continuity of data collection, and documentation to ensure that meaningful trends can be derived.

Another key concept for climate change science is the ability to generate, analyze, and archive long-term climate data records (CDRs) for assessing the state of the environment in perpetuity. In *Climate Data Records from Environmental Satellites* (2004), a climate data record is defined as a time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change. The report identifies several elements of successful climate data record generation programs, ranging from effective, expert leadership to long-term commitment to sustaining the observations and archives.

INTEGRATING KNOWLEDGE AND DATA ON CLIMATE CHANGE THROUGH MODELS

An important concept that emerged from early climate science in the 1980s was that Earth's climate is not just a collection of long-term weather statistics, but rather the complex interactions or "couplings" of the atmosphere, the ocean, the land, and plant and animal life. Climate models are built using our best scientific knowledge, first modeling each process component separately and then linking them together to simulate these couplings.

Climate models are important tools for understanding how the climate operates today, how it may have functioned differently in the past, and how it may evolve in the future in response to forcings from both natural processes and human activities. Climate scientists can deal with uncertainty about future climate by running models with different assumptions of future population growth, economic development, energy use, and policy choices, such as those that affect air quality or influence how nations share technology. Models then offer a range of outcomes based on these different assumptions.

MODELING CAPABILITY AND ACCURACY

Since the first climate models were pioneered in the 1970s, the accuracy of models has improved as the number and quality of observations and data have increased, as computational abilities have multiplied, and as our theoretical understanding of the climate system has improved. Whereas early attempts at modeling used relatively crude representations of the climate, today's models have very sophisticated and carefully tested treatment of hundreds of climate processes.

The National Academies' report *Improving Effectiveness of U.S. Climate Modeling* (2001) offers several recommendations for strengthening climate modeling capabilities, some of which have already been adopted in the United States. At the time the report was published, U.S. modeling capabilities were lagging behind some other countries. The report identified a shortfall in computing facilities and highly skilled technical workers devoted to climate modeling. Federal agencies have begun to centralize their support for climate modeling efforts at the National Center for Atmospheric Research and the Geophysical Fluid Dynamics Laboratory. However, the U.S. could still improve the amount of resources it puts toward climate modeling as recommended in *Planning Climate and Global Change Research* (2003).

CLIMATE CHANGE IMPACTS WILL BE UNEVEN

There will be winners and losers from the impacts of climate change, even within a single region, but globally the losses are expected to outweigh the benefits. The regions that will be most severely affected are often the regions that are the least able to adapt. For example, Bangladesh, one of the poorest nations in the world, is projected to lose 17.5% of its land if sea level rises about 40 inches (1 m), displacing tens of thousands of people. Several islands throughout the South Pacific and Indian Oceans will beat similar risk of increased flooding and vulnerability to storm surges. Coastal flooding likely will threaten animals, plants, and fresh water supplies. Tourism and local agriculture could be severely challenged.

Wetland and coastal areas of many developed nations including United States are also threatened. For example, parts of New Orleans are as much as eight feet below sea level today. However, wealthy countries are much more able to adapt to sea level rise and threats to agriculture. Solutions could include building, limiting or changing construction codes in coastal zones, and developing new agricultural technologies.

The Arctic has warmed at a faster rate than the Northern Hemisphere over the past century. *A Vision for the International Polar Year 2007-2008* (2004) reports that this warming is associated with a number of impacts including: melting of sea ice, which has important impacts on biological systems such as polar bears, ice-dependent seals, and local people for whom these animals are a source of food; increased snow and rainfall, leading to changes in river discharge and tundra vegetation; and degradation of the permafrost.

PREPARING FOR CLIMATE CHANGE

One way to begin preparing for climate change is to make the wealth of climate data and information already collected more accessible to a range of users who could apply it to inform their decisions. Such efforts, often called "climate services," are analogous to the efforts of the National Weather Service to provide useful weather information. Climate is becoming increasingly important to public and private decision making in various fields such as emergency management planning, water quality, insurance premiums, irrigation and power production decisions, and construction schedules. *A Climate Services Vision* (2001) outlines principles for improving climate services that include making climate data as user-friendly as weather services are today, and active and well-defined connections among the government agencies, businesses, and universities involved in climate change data collection and research.

Another avenue would be to develop practical strategies that could be used to reduce economic and ecological systems' vulnerabilities to change. Such "no-regrets" strategies, recommended in *Abrupt Climate Change: Inevitable Surprises* (2002), provide benefits whether a significant climate change ultimately occurs or not, potentially reducing vulnerability at little or no net cost. No-regrets measures could include low-cost steps to: improve climate forecasting; slow biodiversity loss; improve water, land, and air quality; and make institutions—such as the health care enterprise, financial markets, and transportation systems—more resilient to major disruptions.

REDUCING THE CAUSES OF CLIMATE CHANGE

The climate change statement issued in June 2005 by 11 science academies, including the National Academy of Sciences, stated that despite remaining unanswered questions, the scientific understanding of climate change is now sufficiently clear to justify nations taking cost-effective steps that will contribute to substantial and long-term reduction in net global greenhouse gas emissions. Because carbon dioxide and some other greenhouse gases can remain in the atmosphere for many decades and major parts of the climate system respond slowly to changes in greenhouse gas concentrations, climate change impacts will likely continue throughout the 21st century and beyond. Failure to implement significant reductions in net greenhouse gas emissions now will make the job much harder in the future—both in terms of stabilizing their atmospheric abundances and in terms of experiencing more significant impacts.

At the present time there is no single solution that can eliminate future warming. As early as 1992, *Policy Implications of Greenhouse Warming* found that there are many potentially cost-effective technological options that could contribute to stabilizing greenhouse gas concentrations.

MEETING ENERGY NEEDS IS A MAJOR CHALLENGE TO SLOWING CLIMATE CHANGE

Energy—either in the form of fuels used directly (i.e., gasoline) or as electricity produced using various fuels (fossil fuels as well as nuclear, solar, wind, and others)—is essential for all sectors of the economy, including industry, commerce, homes, and transportation. Energy use worldwide continues to grow with economic and population growth. Developing countries, China and India in particular, are rapidly increasing their use of energy, primarily from fossil fuels, and consequently their emissions of CO_2. Carbon emissions from energy can be reduced by using it more efficiently or by switching to alternative fuels. It also may be possible to capture carbon emissions from electric generating plants and then sequester them.

Energy efficiency in all sectors of the U.S. economy could be improved. The 2002 National Academies' report, *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*, evaluates car and light truck fuel use and analyzes how fuel economy could be improved. Steps range from improved engine lubrication to hybrid vehicles. The 2001 Academies report, *Energy Research at DOE, Was It Worth It?* addresses the benefits of increasing the energy efficiency of lighting, refrigerators and other appliances. Many of these improvements (e.g., high-efficiency refrigerators) are cost-effective means to significantly reducing energy use, but are being held back by market constraints such as consumer awareness, higher initial costs, or by the lack of effective policy.

Electricity can be produced without significant carbon emissions using nuclear power and renewable energy technologies (e.g., solar, wind, and biomass). In the United States, these technologies are too expensive or have environmental or other concerns that limit broad application, but that could change with technology development or if the costs of fossil fuels increase. Replacing coal-fired electric power plants with more efficient, modern natural-gas-fired turbines would reduce carbon emissions per unit of electricity produced.

Several technologies are being explored that would collect CO_2 that would otherwise be emitted to the atmosphere from fossil-fuel-fired power plants, and then sequester it in the ground or the ocean. Successful, cost-effective sequestration technologies would weaken the link between fossil fuels and greenhouse gas emissions. The 2003 National Academies' report, *Novel Approaches to Carbon Management: Separation, Capture, Sequestration, and Conversion to Useful Products*, discusses the development of this technology.

Capturing CO_2 emissions from the tailpipes of vehicles is essentially impossible, which is one factor that has led to considerable interest in hydrogen as a fuel. As with electricity, hydrogen must be manufactured from primary energy sources. Significantly reducing carbon emissions when producing hydrogen from fossil fuels (currently the least expensive method) would require carbon capture and sequestration. Substantial technological and economic barriers in all phases of the hydrogen fuel cycle must first be addressed through research and development. The 2004 National Academies' report, The *Hydrogen Economy: Opportunities, Costs, Barriers and R&D Needs*, presents a strategy that could lead eventually to production of hydrogen from a variety of domestic sources—such as coal (with carbon sequestration), nuclear power, wind, or photo-biological processes—and efficient use in fuel cell vehicles.

CONTINUED SCIENTIFIC EFFORTS TO ADDRESS A CHANGING CLIMATE

The task of mitigating and preparing for the impacts of climate change will require worldwide collaborative inputs from a wide range of experts, including natural scientists, engineers, social scientists, medical scientists, those in government at all levels, business leaders, and economists. Although the scientific understanding of climate change has advanced significantly in the last several decades, there are still many unanswered questions. Society faces increasing pressure to decide how best to respond to climate change and associated global changes, and applied research in direct support of decision making is needed.

The CHAIRMAN. We are going to take Sir John Houghton next, even though I stated otherwise. Please proceed, sir.

STATEMENT OF SIR JOHN HOUGHTON, CO-CHAIRMAN, SCIENTIFIC ASSESSMENT WORKING GROUP, INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, LONDON, ENGLAND

Sir HOUGHTON. Thank you very much, indeed. I consider it a privilege to be asked to testify to your committee this morning. Thank you for inviting me.

On my last visit to the United States in March I was briefing the National Association of Evangelicals, though a different body, and was most pleased to find that large and influential body engaging with this issue of global climate change, which is the most serious environmental issue which is facing the world today.

Regarding the science of human-induced climate change as currently understood, it is actually summarized succinctly in last month's resolution in the Senate, which states that the major impacts will come through sea level rise and through increases in the frequency and the intensity of extreme events, such as droughts and floods. Those are the most damaging disasters the world knows.

An example of an extreme for which we can say with some certainty that the growth of greenhouse gases was largely responsible is the European heat wave in the summer of 2003 that lead to the deaths of over 20,000 people.

I said more about the science in my written evidence. Here, I would like to say a little more about the Intergovernmental Panel on Climate Change, which is the source of much of the scientific information that we have, and about which a lot of misinformation has been propagated.

I had the privilege of being chairman or co-chairman of the Panel of Scientific Assessments from its formation in 1988 to 2002. The IPCC's latest report in 2001, it is in four volumes, each of 1,000 pages each, contains many thousands of references to the scientific literature. And many hundreds of scientists were involved in the writing and review processes.

The report went through two major reviews, first by scientists. And any scientist, who wished, could take part. And second, by governments. No assessments on any other scientific topic has been so thoroughly researched and reviewed.

IPCC reports are being produced in a very open process under the discipline of science, where honesty and balance are hallmarks of that discipline. Influence from personal or political agendas were ruled out, and I made absolutely sure of that in my role as chairman. We had many days of lively debate, and scientists, of course, are their own best critics.

I remember, after a very hectic meeting, at the end of one of our reports, two scientists from the aviation industry who were joined as lead authors for that report, came to me and expressed their delight with the IPCC experience. They said never had they before been involved in a report for which the conclusions were not known before it was written.

Very strong endorsement has been given to the IPCC from the world's scientific community. Last month, in a completely unprecedented action, a statement was issued by the science academies of all the G8 countries, together with the academies of Brazil, China, and India, endorsing the IPCC's work and conclusions. With that strong statement from the world's leading scientists, there can be no doubt about the reality and seriousness of human-induced climate change.

One of the main tasks of the IPCC has to be distinguished between what is well known and understood from those areas with large uncertainty. In 1992, in the Framework Convention on Climate Change, agreed by all countries, and signed for the United States by President George H.W. Bush, it was already stated that enough was known for action to be taken. Since then, the science has become substantially more certain. IPCC reports have consistently proved to be too conservative.

Many suggest why do we not just wait and see before taking action. There are strong reasons for urgent action. The first is scientific. Because the oceans take time to warm, there is a lag in the response of climate to increasing gases. So far we have only experienced a small part of the climate response to the emissions that have already occurred.

If emissions were halted tomorrow, over the next 30 years or more we would experience a growing level of impacts at least two or three times those we have seen already. Further emissions just added to that commitment.

The second reason for the urgent action is economic. Energy infrastructure, for instance, in power stations also lasts typically for 30 to 50 years.

The third reason is political. Countries like China and India are industrializing very rapidly. I heard a senior energy advisor to the Chinese government speak recently. He said that China by itself would not be making big moves to non-fossil fuel sources. When the developing nations of the West take action, they will take action. They will follow, not lead.

To move the world forward, we have to be seen ourselves to be moving. I hope, Mr. Chairman, you will allow me just to say a little about the need for leadership if I may, in conclusion.

People often say to me I am wasting my time talking about global warming. The world, they say, will never agree to take the necessary action. I reply I am optimistic for three reasons. First, I have experienced the commitment of the world's scientific community. Second, I believe the necessary technology is available for achieving satisfactory solutions. Third, I believe as a Christian that God is committed to his creation, and that we have a God-given task of being good stewards of creation, a task that we do not have to accomplish on our own, because God is there to help us with it.

And then a final paragraph, if I may. In my work with the IPCC, I have been privileged to work with many climate scientists in the United States who are world leaders in their field. The United States is also a world leader in the technologies required. The overall challenge is to move close to a zero carbon economy within a generation. The means to do that are available. The challenge and the opportunities to our scientists and our industries are very large. But science and technology are only part of what is needed. The challenge is global and requires a global solution.

Mr. Chairman, the moves recently made by the Senate to develop a strategy for addressing the issue of human-induced climate change are of tremendous importance. Is it too much to hope that they are the start of a bid for leadership by the United States in the wide world, as all countries, both developed and developing, set out to meet this challenge together? The world is watching what the United States and, indeed, what this committee will do. Thank you very much.

The CHAIRMAN. Well, thank you very much.

[The prepared statement of Sir Houghton follows:]

PREPARED STATEMENT OF SIR JOHN HOUGHTON, CO-CHAIRMAN, SCIENTIFIC ASSESSMENT WORKING GROUP, INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, LONDON, ENGLAND

I consider it a privilege to be asked to testify to your committee this morning. Thank you for inviting me. On my last visit to the United States in March I was briefing the National Association of Evangelicals and was most pleased to find that large and influential body engaging with this issue of global climate change—the most serious environmental issue facing the world today.

THE BASIC SCIENCE OF GLOBAL WARMING

Let me start with a quick summary of the basic science of Global Warming. By absorbing infra-red or 'heat' radiation from the earth's surface, 'greenhouse gases' present in the atmosphere, such as water vapour and carbon dioxide, act as blankets over the earth's surface, keeping it warmer than it would otherwise be. The existence of this natural 'greenhouse effect' has been known for nearly two hundred years; it is essential to the provision of our current climate to which ecosystems and we humans have adapted.

Since the beginning of the industrial revolution around 1750, one of these greenhouse gases, carbon dioxide has increased by over 30% and is now at a higher concentration in the atmosphere than it has been for many hundreds of thousands of years (Fig 1).* Chemical analysis demonstrates that this increase is due largely to the burning of fossil fuels—coal, oil and gas. If no action is taken to curb these emissions, the carbon dioxide concentration will rise during the 21st century to two or three times its preindustrial level.

Fig 1. Concentration of carbon dioxide in the atmosphere from 1000 AD and projected to 2100 under typical IPCC scenarios.[1]

Fig 2. Variations of the average near surface air temperature: 1000-1861, N Hemisphere from proxy data; 1861-2000, global instrumental; 2000-2100, under a range of IPCC projections with further shading to indicate scientific uncertainty.[2]

The climate record over the last 1000 years (Fig 2) shows a lot of natural variability—including, for instance, the 'medieval warm period' and the 'little ice age'.[3]

*Figures 1-6d have been retained in committee files.

[1] From IPCC 2001 Synthesis Report published by Cambridge University Press 2001.

[2] From IPCC 2001 Synthesis Report published by Cambridge University Press 2001.

[3] Since the IPCC 2001 report there has been a debate in the scientific literature regarding the statistical procedures for reconstruction of the proxy part of the record that might affect its overall shape especially over the 14th to the 19th centuries (the little ice age period)—see for instance von Storch et al. 2004, Science 306 621-2. This 'hockey-stick' debate, however, does not significantly influence the main IPCC conclusions regarding the temperature of the 20th century.

The rise in global average temperature (and its rate of rise) during the 20th century is well outside the range of known natural variability. The year 1998 is the warmest year in the instrumental record. A more striking statistic is that each of the first 8 months of 1998 was the warmest on record for that month. There is strong evidence that most of the warming over the last 50 years is due to the increase of greenhouse gases, especially carbon dioxide. Confirmation of this is also provided by observations of the warming of the oceans.[4] The period of 'global dimming' from about 1950 to 1970 is most likely due to the increase in atmospheric particles (especially sulphates) from industrial sources. These particles reflect sunlight, hence tending to cool the surface and mask some of the warming effect of greenhouse gases. Global climate models[5] that include human induced effects (greenhouse gas increases and particles) and known natural forcings (e.g. variations in solar radiation and the effects of volcanoes) can provide good simulations of the 20th century profile of global average temperature change.

Over the 21st century the global average temperature is projected to rise by between 2 and 6° C (3.5 to 11° F) from its preindustrial level; the range represents different assumptions about emissions of greenhouse gases and the sensitivity of the climate model used in making the estimate (Fig 2). For global average temperature, a rise of this amount is large. The difference between the middle of an ice age and the warm periods in between is only about 5 or 6° C (9 to 11° F). So, associated with likely warming in the 21st century will be a rate of change of climate equivalent to say, half an ice age in less than 100 years—a larger rate of change than for at least 10,000 years. Adapting to this will be difficult for both humans and many ecosystems.

THE IMPACTS OF HUMAN INDUCED CLIMATE CHANGE

Talking in terms of changes of global average temperature, however, tells us rather little about the impacts of global warming on human communities. Some of the most obvious impacts will be due to the rise in sea level that occurs because ocean water expands as it is heated. The projected rise is of the order of half a metre (20 inches) a century and will continue for many centuries—to warm the deep oceans as well as the surface waters takes a long time. This will cause large problems for human communities living in low lying regions, for instance in the Everglades region of Florida. Many areas, for instance in Bangladesh (where about 10 million live within the one metre contour—Fig 3), southern China, islands in the Indian and Pacific oceans and similar places elsewhere in the world, will be impossible to protect and many millions will be displaced.

Fig 3. Land affected in Bangladesh by various amounts of sea level rise

There will also be impacts from extreme events. The extremely unusual high temperatures in central Europe during the summer of 2003 led to the deaths of over 20,000 people. Careful analysis shows that it is very likely that a large part of the cause of this event is due to increases in greenhouse gases and projects that such summers are likely to be the norm by the middle of the 21st century and cool by the year 2100.

Water is becoming an increasingly important resource. A warmer world will lead to more evaporation of water from the surface, more water vapour in the atmosphere and more precipitation on average. Of greater importance is the fact that the increased condensation of water vapour in cloud formation leads to increased latent heat of condensation being released. Since this latent heat release is the largest source of energy driving the atmosphere's circulation, the hydrological cycle will become more intense. This means a tendency to more intense rainfall events and also less rainfall in some semi-arid areas. Since, on average, floods and droughts are the most damaging of the world's disasters (see box), their greater frequency and intensity is bad news for most human communities and especially for those regions such as south east Asia and sub-Saharan Africa where such events already occur only too frequently.

[4] See recent paper by J. Hansen et al. in Sciencexpress for 28 April 2005/10.1126/science.1110252

[5] Global climate models run on large computers include all components of the climate system (atmosphere, land, oceans, ice and biosphere) with global coverage, include algorithmic descriptions of all physical processes and integrate the dynamical equations to provide simulations of current climate or projections of future climate. They are powerful tools that add together the effects of all the non linear processes involved.

MAJOR FLOODS IN THE 1990S

- 1991, 1994-5, 1998—China; average disaster cost 1989-96, 4% of GDP
- Mississipi & Missouri, U.S.A.; flooded area equal to one of great lakes
- 1997—Europe; 162,000 evacuated and > 5bn $ loss
- 1998—Hurricane Mitch in central America; 9000 deaths, economic loss in Honduras & Nicaragua 70% & 45% of GDP
- 1999—Venezuela; flooding led to landslide, 30,000 deaths
- 2000-1—Mozambique; two floods leave more than half a million homeless

Regarding extreme events and disasters, it is often pointed out that climate possesses large natural variability and such events have been common occurrences over the centuries. It is not possible, for instance, when a disaster occurs to attribute that particular event to increasing greenhouse gases (except perhaps for the 2003 heat wave mentioned above). So, what is the evidence that they will increase in a globally warmed world? First, there is our understanding of the basic science of climate change that I have briefly outlined. Secondly, increasing evidence is provided from observations. Significant increases have been observed in the number of intense rainfall events especially over areas like the U.S.A. where there is good data coverage. Data from insurance companies show an increase in economic losses in weather related disasters of a factor of 10 in real terms between the 1950s and the 1990s. Some of this can be attributed to an increase in vulnerability to such disasters. However, a significant part of the trend has also arisen from increased storminess especially in the 1980s and 1990s.

Thirdly, increased risk of heat waves, floods and droughts are some of the most robust projections of climate models that take into account in a comprehensive way all the physical and dynamical processes involved in climate change. For instance, a study for the area of central Europe, with doubled atmospheric carbon dioxide concentration (likely to occur during the second half of the 21st century), indicates an decrease in the return period of flooding events by about a factor of five (e.g. from 50 years to 10 years).[6]

Tropical cyclones are particular damaging storms that occur in the sub tropics. They require special mention because no evidence exists for an increase in their number as the earth warms although an increase is considered likely in peak wind and precipitation intensities in such systems. Sea level rise, changes in water availability and extreme events will cause the most damaging impacts of human induced climate change.[7] They will lead to increasing pressure from many millions of environmental refugees.

In addition to the main impacts summarised above are changes about which there is less certainty, but if they occurred would be highly damaging and possibly irreversible. For instance, large changes are being observed in polar regions. If the temperature rises more than about 3° C (approximately 5° F) in the area of Greenland, it is estimated that melt down of the ice cap would begin. Complete melt down is likely to take 1000 years or more but it would add 7 metres (23 feet) to the sea level.

A further concern is regarding the Thermo-Haline Circulation (THC)—a circulation in the deep oceans, partially sourced from water that has moved in the Gulf Stream from the tropics to the region between Greenland and Scandinavia. Because of evaporation on the way, the water is not only cold but salty, hence of higher density than the surrounding water. It therefore tends to sink and provides the source for a slow circulation at low levels that connects all the oceans together. This sinking assists in maintaining the Gulf Stream itself. In a globally warmed world, increased precipitation together with fresh water from melting ice will decrease the water's salinity making it less likely to sink. The circulation will therefore weaken and possibly even cut off, leading to large regional changes of climate. All climate models indicate the occurrence of this weakening. Evidence from paleoclimate history shows that such cut-off has occurred at times in the past. It is such an event that is behind the highly speculative happenings in the film, *The day after tomorrow*.

I have spoken so far about adverse impacts. However, there are some positive impacts. For instance, in Siberia and other areas at high northern latitudes, winters will be less cold and growing seasons will be longer. Also, increased concentrations of carbon dioxide have a fertilising effect on some plants and crops which, providing

[6] Palmer, T.N., and Raisanen, J., 2002, *Nature*, 415, 512-14.

[7] Many of the studies addressing the cost of global warming impacts fail to take account of the cost of extremes as is explained in Houghton, Global Warming: the Complete Briefing, CUP 2004, chapter 7.

there are adequate supplies of water and nutrients, will lead to increased crop yields in some places, probably most notably in northern mid latitudes. However, careful studies demonstrate that adverse impacts will far outweigh positive effects, the more so as temperatures rise more than 1 or 2° C (2 to 3.5° F) above preindustrial.

Many people ask how sure we are about the scientific story I have just presented. Let me explain that it is based very largely on the extremely thorough work of the Intergovernmental Panel on Climate Change (IPCC) and its last major report published in 2001. The scientific literature on climate change has increased enormously over the last decade. The basic science of anthropogenic climate change has been confirmed. The main uncertainties lie in our knowledge of feedbacks in the climate system especially those associated with the effects of clouds. Recent research has tended to indicate increased likelihood of the more damaging impacts.

THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC)

Let me explain more about the work of the IPCC. It was formed in 1988 jointly by the World Meteorological Organisation and the United Nations Environment Programme. I had the privilege of being chairman or co-chairman of the Panel's scientific assessment from 1988 to 2002. Hundreds of scientists drawn from many countries were involved as contributors and reviewers in these assessments. The IPCC has produced three assessments—in 1990, 1995 and 2001—covering science, impacts and analyses of policy options. The IPCC 2001 report is in four volumes each of about 1000 pages and containing many thousands of references to the scientific literature.[8] Each chapter of the Report went through two major reviews, first by hundreds of scientists in the scientific community (any scientist who wished could take part in this) and secondly, by governments. No assessment on any other scientific topic has been so thoroughly researched and reviewed.

Because the IPCC is an intergovernmental body, the reports' Summaries for Policymakers were agreed sentence by sentence by meetings in which governmental delegates from about 100 countries (including all the world's major countries) work with around 40 leading scientists representing the scientific community. It is sometimes supposed that the presence of governments implies political interference with the process. That has not been the case. In any event, governments taking part come from the complete spectrum of political agendas. These are scientific meetings in which all proposals for changes in the text must be based either on scientific arguments or on a desire for clearer presentation. In every case, the process has resulted in documents with overall improved scientific clarity and balance.

The work of the IPCC is backed by the worldwide scientific community. A joint statement of support was issued in May 2001 by the national science academies of Australia, Belgium, Brazil, Canada, the Caribbean, China, France, Germany, India, Indonesia, Ireland, Italy, Malaysia, New Zealand, Sweden and the U.K. It stated *'We recognize the IPCC as the world's most reliable source of information on climate change and its causes, and we endorse its method of achieving consensus.'* In 2001, a report of the United States National Academy of Sciences commissioned by the President George W. Bush administration, supported the IPCC's conclusions.[9] A joint statement issued in June 2005 by the science academies of all the G8 countries together with the academies of Brazil, China and India also endorsed the work and conclusions of the IPCC.[10]

Let me comment further on the issues of uncertainty and balance as expressed in the work of the IPCC. There are very large amounts of data available to the scientist looking for evidence of climate change. Examples abound of those who approach the data with preconceived agendas and who have selected data to fit those agendas—for instance purporting to prove either that there is little or no evidence for human induced change or that the world is heading for a future that could mean the end of the human race. The task of the IPCC has been to review *all* the evidence in a balanced manner and honestly and objectively to distinguish what is reasonably well known and understood from those areas with large uncertainty. The reports have differentiated between degrees of uncertainty, where possible providing numerical estimates of uncertainty. A large part of the IPCC process, taking many days

[8] Climate Change 2001 in four volumes, published for the IPCC by Cambridge University Press, 2001. Also available on the IPCC web site *www.ipcc.ch*. My book, John Houghton, *Global Warming: the complete briefing*, 3'd edition, Cambridge University Press, 2004 is strongly based on the IPCC reports. Further a review I have recently written (John Houghton, Global Warming, Reports Progress in Physics, 68 (2005) 1343-1403) provides a concise summary of the science and associated impacts.

[9] *http://books.nap.edu/html/climatechange/*

[10] *http://nationalacademies.org/morenews/*

of scientists' time, has been taken up with discussion and correspondence about how best to present uncertainty.

Let me mention a further point on the uncertainty issue. In the IPCC reports, because they are scientific documents, uncertainty tends to be mentioned frequently giving the impression to the casual reader that the uncertainty in the conclusions is larger than it is in many other areas of our experience with which comparison could be made. What is important to realise is that there is a high degree of certainty that significant human induced climate change is occurring and will continue to occur. A forecast of little or no such climate change is almost certainly wrong.

THE FRAMEWORK CONVENTION ON CLIMATE CHANGE

Because of the work of the IPCC and its first report in 1990, the Earth Summit at Rio de Janeiro in 1992 could address the climate change issue and the action that needed to be taken. The Framework Convention on Climate Change (FCCC)—agreed by over 160 countries, signed by President George Bush Sr. for the U.S.A. and subsequently ratified unanimously by the U.S. Senate—agreed that Parties to the Convention should take *"precautionary measures to anticipate, prevent or minimise the causes of climate change and mitigate its adverse effects. Where there are threats of irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures."*

More particularly the Objective of the FCCC in its Article 2 is "to stabilise greenhouse gas concentrations in the atmosphere at a level that does not cause dangerous interference with the climate system" and that is consistent with sustainable development. Such stabilisation would also eventually stop further climate change. However, because of the long time that carbon dioxide resides in the atmosphere, the lag in the response of the climate to changes in greenhouse gases (largely because of the time taken for the ocean to warm), and the time taken for appropriate human action to be agreed, the achievement of such stabilisation will take at least the best part of a century.

STABILIZATION OF CARBON DIOXIDE

Global emissions of carbon dioxide to the atmosphere from fossil fuel burning are currently approaching 7 billion tonnes of carbon per annum and rising rapidly (Fig 4). Unless strong measures are taken they will reach two or three times their present levels during the 21st century and stabilisation of greenhouse gas concentrations or of climate will be nowhere in sight. To stabilise carbon dioxide concentrations in accordance with the FCCC Objective, emissions during the 21st century must reduce to a fraction of their present levels before the century's end.

The reductions in emissions must be made globally; all nations must take part. However, there are very large differences between greenhouse gas emissions in different countries. Expressed in tonnes of carbon per capita per annum, they vary from about 5.5 for the U.S.A., 2.2 for Europe, 0.7 for China and 0.2 for India (Fig 5). Ways need to be found to achieve reductions that are both realistic and equitable.

Fig 4. Global emissions of carbon dioxide from fossil fuel burning (in billions of tonnes of carbon) up to 1990 and as projected to 2100 under World Energy Council scenarios,[11] A's and B's with various 'business as usual assumptions' and C for 'ecologically driven scenario' that would lead to stabilisation of carbon dioxide concentration at about 450 ppm.

Fig 5. Carbon dioxide emissions in 2000 per capita for different countries and groups of countries.[12]

The Kyoto Protocol set up by the FCCC represents a beginning for the process of reduction, averaging about 5% below 1990 levels by 2012 by those developed countries who have ratified the protocol. It is an important start demonstrating the achievement of a useful measure of international agreement on such a complex issue. It also introduces for the first time international trading of greenhouse gas emissions so that reductions can be achieved in the most cost effective ways.

Serious discussion is now beginning about international agreements for emissions reductions post Kyoto. These must include all major emitters in both developed and developing countries. On what eventual level of stabilisation, of carbon dioxide for instance, should these negotiations focus? To stop damaging climate change the level needs to be as low as possible. In the light of the FCCC Objective it must also

[11] From Energy for Tomorrow's World: the realities, the real options and the agenda for achievement. World Energy Council Report 1993.

[12] After M. Grubb 2003, World Economics 3, p. 145.

allow for sustainable development. Let me give two examples of stabilisation proposals. In 1996 the European Commission proposed a limit for the rise in global average temperature from its preindustrial value of 2° C—that implies a stabilisation level for carbon dioxide of about 430 ppm (allowing for the effect of other greenhouse gases at their 1990 levels). The second example comes from Lord John Browne, Chief Executive Officer of British Petroleum, one of the world's largest oil companies, who in a recent speech proposed 'stabilisation in the range 500-550 ppm' that 'with care could be achieved without disrupting economic growth.'

Let us consider carbon dioxide stabilisation at 500 ppm. If the effect of other greenhouse gases at their 1990 levels is added, it is about equivalent to doubled carbon dioxide at its preindustrial level and a rise in global averaged temperature of about 2.5° C. Although climate change would eventually largely be halted—although not for well over a hundred years—the climate change impacts at such a level would be large. A steady rise in sea level will continue for many centuries, heat waves such as in Europe in 2003 would be commonplace, devastating floods and droughts would be much more common in many places and Greenland would most likely start to melt down. The aim should be therefore to stabilise at a lower level. But is that possible?

The International Energy Agency (TEA) in 2004 published a *World Energy Outlook* that in their words 'paints a sobering picture of how the global energy system is likely to evolve from now to 2030'. With present governments' policies, the world's energy needs will be almost 60% higher in 2030 that they are now. Fossil fuels will dominate, meeting most of the increase in overall energy use. Energy-related emissions of carbon dioxide will grow marginally faster than energy use and will be more than 60% higher in 2030 than now (Fig 6, reference scenario). Over two-thirds of the projected increase in emissions will come from developing countries.

Fig 6. Carbon dioxide emissions from fossil fuel burning and profile leading to stabilisation at 500 ppm (a, b and c) and 450 ppm (d). Emissions data from International Energy Agency scenarios;[13] reference (a), alternative (b) for developed countries (red) and developing (blue). For (c) and (d) see text.

The *Outlook* also presents an Alternative Scenario that analyses the global impact of environmental and energy-security policies that countries around the world are already considering as well as the effects of faster deployment of energy-efficient technologies. However, even in this scenario, global emissions in 2030 are substantially greater than they are today (Fig 6). Neither scenario comes close to creating the turn around in the global profile required.

The U.K. government has taken a lead on this issue and has agreed a target for the reduction of greenhouse gas emissions of 60% by 2050—predicated on a stabilisation target of doubled carbon dioxide concentrations together with a recognition that developed countries will need to make greater reductions to allow some headroom for developing countries. Economists in the U.K. government Treasury Department have estimated the cost to the U.K. economy of achieving this target. On the assumption of an average growth in the U.K. economy of 2.25% p.a., they estimated a cost of no more than the equivalent of 6 months' growth over the 50 year period. Similar costs for achieving stabilisation have been estimated by the IPCC.

The effect of a reduction of 60% on average by developed countries is shown in Fig 6(c) together with a scenario for developing countries that increases by 1% p.a. until 2030 followed by level emissions to 2050. For this the 500 ppm curve is approximately followed but for developing countries to be satisfied with such a modest growth presents a very large challenge. Even more challenging for both developed and developing countries would be the measures required to stabilise at 450 ppm (Fig 6(d)). Governor Schwarzenegger of California has begun to address this challenge by proposing an even more demanding reduction target of 80% by 2050.

CAN WE WAIT AND SEE?

In order to achieve reductions on the scale that is required to stabilize carbon dioxide concentrations, large changes will have to occur in way we use energy (through energy efficiency improvements) and generate it (through moves to energy sources with zero or low carbon emissions). But how urgent are the changes required. It is sometimes suggested that we can 'wait and see' before serious action is needed. This is an area where policy needs to be informed by the perspective from science.

[13] From World Energy Outlook, LEA 2004.

There is a strong *scientific* reason for urgent action. Because the oceans take time to warm, there is a lag in the response of climate to increasing greenhouse gases. So far we have only experienced a small part of the climate response to the greenhouse gas emissions that have already occurred. If greenhouse gas emissions were halted tomorrow, climate impacts much greater than we have so far experienced but to which we are already committed will be realized over the next 30 years and more into the future.[14] Further emissions from now on just add to that commitment. It is for this reason that the June 2005 statement from the world's major science academies urges all nations,[15] *'to take prompt action to reduce the causes of climate change and adapt to its impacts' and to 'identify cost-effective steps that can be taken now to contribute to substantial and long-term reduction in net global greenhouse gas emissions, recognizing that delayed action will increase the risk of adverse environmental effects and will likely incur a greater cost.'*

Two further reasons can be identified for urgent action. One is economic. Energy infrastructure, for instance in power stations also lasts typically for 30 to 50 years. As was stated by the leaders of the G8 countries meeting at Gleneagles in the U.K. earlier this month,[16] *We face a moment of opportunity. Over the next 25 years, an estimated $16 trillion will need to be invested in the world's energy systems. According to the IEA, there are significant opportunities to invest this capital cost-effectively in cleaner energy technologies and energy efficiency. Because decisions being taken today could lock in investment and increase emissions for decades to come, it is important to act wisely now.*

A third reason is *political*. Countries like China and India are industrialising very rapidly. I heard a senior energy adviser to the Chinese government speak recently. He said that China by itself would not be making big moves to non fossil fuel sources. When the developed nations of the west take action, they will take action—they will follow not lead. China is building new electricity generating capacity of about 1 GW power station per week. To move the world forward we have to be seen ourselves to be moving.

THE U.K. AND CLIMATE CHANGE

I would like to add a few remarks about the U.K. and climate change. It was Prime Minister Margaret Thatcher who in 1988, speaking as a scientist as well as a political leader, was one of the first to bring the potential threat of global warming to world attention. Subsequent U.K. governments have continued to play a leading international role in this issue. This year, Prime Minister Tony Blair has put climate change at the top of his agenda for his presidency of the G8 and the EU.

This international activity has brought the realisation within the U.K. government that a big environmental issue such as climate change needs to be brought much closer to the centre of the government machine. For instance, Gordon Brown, U.K.'s Chancellor of the Exchequer has clearly stated the importance of addressing the economy and environment together. In a recent speech he said,[17] 'Environmental issues—including climate change—have traditionally been placed in a category separate from the economy and from economic policy. But this is no longer tenable. Across a range of environmental issues—from soil erosion to the depletion of marine stocks, from water scarcity to air pollution—it is clear now not just that economic activity is their cause, but that these problems in themselves threaten future economic activity and growth.'

THE NEED FOR LEADERSHIP

We, in the developed countries have already benefited over many generations from abundant and cheap fossil fuel energy—although without realising the potential damage to the climate and especially the disproportionate adverse impacts falling on the poorer nations. The Framework Convention on Climate Change (FCCC) recognized the particular responsibilities this placed on developed countries to be the first to take action and to provide assistance (e.g. through appropriate finance and technology transfer) to developing countries for them to cope with the impacts and to develop cost effective sources of energy free of carbon emissions. The moral imperative created by these responsibilities is reflected in the statement on climate change made by the leaders of the G8 countries meeting at Gleneagles in the fol-

[14] See recent paper by J. Hansen et al. in Sciencexpress for 28 April 2005/10.1126/science.1110252

[15] *http://nationalacademies.org/morenews/*

[16] *http://www.g8.gov.uk*

[17] Address to the Energy and Environment Ministerial Roundtable, 15 March 2005; *http://www.hm-treasury.gov.uk/newsroom__and__speeches/press/2005/press__29__05.cfm*

lowing paragraph,[18] *'It is in our global interests to work together, and in partnership with major emerging economies, to find ways to achieve substantial reductions in greenhouse gas emissions and our other key objectives, including the promotion of low-emitting energy systems. The world's developed economies have a responsibility to act.'*

People often say to me that I am wasting my time talking about Global Warming. 'The world' they say 'will never agree to take the necessary action'. I reply that I am optimistic for three reasons. First, I have experienced the commitment of the world scientific community (including scientists from many different nations, backgrounds and cultures) in painstakingly and honestly working together to understand the problems and assessing what needs to be done. Secondly, I believe the necessary technology is available for achieving satisfactory solutions. My third reason is that, as a Christian, I believe God is committed to his creation and that we have a God-given task of being good stewards of creation—a task that we do not have to accomplish on our own because God is there to help us with it. As a recent statement on climate change by scientific and religious leaders in the U.S. says:[19] *'What is most required at this moment . . . is moral vision and leadership. Resources of human character and spirit—love of life, far-sightedness, solidarity—are needed to awaken a sufficient sense of urgency and resolve.'*

In my work with the IPCC I have been privileged to work with many climate scientists from the U.S.A. who are world leaders in their field. The U.S.A. is also a world leader in the technologies aimed at reducing greenhouse gas emissions. But science and technology are only part of what is required. Mr. Chairman, the moves recently made by the Senate to develop a strategy for addressing the issue of human induced climate change are of great importance. Is it too much to hope that they are the start of a bid for leadership by the U.S. in the wider world as all countries—both developed and developing—set out to meet this challenge together?

The CHAIRMAN. Now we will proceed in the order that we started.

Dr. Molina.

STATEMENT OF DR. MARIO MOLINA, PROFESSOR, UNIVERSITY OF CALIFORNIA, SAN DIEGO

Dr. MOLINA. I am very pleased to be here to discuss the science of climate change and to reflect on the very real challenge of making sound policy choices in the face of uncertainty. Climate change is, perhaps, the most worrisome global environmental problem confronting human society today. It involves a complex interplay of scientific, economic, and political issues. The impacts of climate change are potentially very large, and will occur over a time scale of decades to centuries.

The actions needed to respond to this challenge require substantial long-term commitments to change traditional economic development paths throughout the world. The ultimate solution to the challenge will require a fundamental transformation in the production and consumption of energy in the United States, but also by developed and developing nations.

I want to address the bulk of my remarks to the threshold question. Do we know enough about climate change to act now and to start doing something serious to address this problem? Let me first comment on what I think the role of scientists should be in answering this question.

Ultimately, policy decisions about climate change have to be made by society at large, and more specifically by policymakers like yourselves. Scientists do not have any special privilege to make

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[18] *http://www.g8.gov.uk*

[19] *From Earth's Climate Embraces Us All: A Plea From Religion and Science for Action on Global Climate Change*, July 2004; available form the National Religious partnership for the Environment at *http://www.nrpe.org/climate__letter.pdf*

such decisions, but science does play a fundamental role on this issue.

The climate system is very complicated, and science does not have all the answers. There are uncertainties in predicting when and to what extent will the climate change as a consequence of a given course of human activities. However, scientists can estimate the probability that the earth's climate will respond in certain ways.

For simplicity, the climate response is often represented as the increasing average global surface temperature of the planet, say, by the end of the century. This information can be used by policymakers to assess the risks imposed by climate change and to devise adequate responses to address the challenge.

Let me simply summarize what we know about climate change, although we just heard the other witnesses, Dr. Cicerone and Sir John Houghton already summarizing these. But I firmly embrace the view expressed in the recent sense of the Senate resolution, namely that there is a growing scientific consensus that human activity is a substantial cause of greenhouse gas accumulation in the atmosphere, "and that these accumulating gases are causing average temperatures to rise at the rate outside of natural variability."

Simply stated, the world is warming. It is due to our emissions. More warming is inevitable, but the amount of future warming is in our hands. Because carbon dioxide accumulates and remains in the atmosphere, each generation inherits the emissions of all those who have gone before. Many future generations of human beings will wrestle with this issue.

Modest amounts of warming will have both positive and negative impacts. But above a certain threshold, the impacts turn strongly negative for most nations, people, and for biological systems.

While there is a growing scientific consensus around the science of climate change, there is, of course, much that we do not fully understand about the timing, geographic distribution, and the severity of the changes in climate, and the economic, environmental and social impacts of these changes that will result if greenhouse gases continue to increase. However, not knowing with certainty how the climate system would respond should not be an excuse for inaction.

Policymakers frequently, in the position of making decisions, they do that in the face of uncertainties. Usually, the presence of uncertainty means that we build extra insurance to protect against the risk that the consequences may be worse than expected. It would be better, of course, if we knew exactly where the perfect balance between costs, risks and benefits lies, but the fact is that we never have that luxury.

Nevertheless, policymakers and the individuals both must manage public and personal risks all the time. And we do. Most people buy car insurance even though they do not know with any degree of certainty what their individual risk of being in a car accident might be, just as most doctors would advise an individual with a history of heart trouble to choose low-fat foods and exercise despite the many complex and usually unknowable factors that go into determining any individual person's risk of having a heart attack.

If we apply the same logic in setting goals for limiting the risks associated with future climate change, it becomes very clear that our current course now places us far outside the kinds of risk thresholds we typically apply in other areas of public policy.

Put another way, there is now an overwhelming consensus that failure to limit greenhouse gas emissions would produce a risk of significant adverse consequences that is far higher than we find acceptable in other arenas. When facing a substantial chance of potentially catastrophic consequences and the near certainty of lesser negative effects, the only prudent course of action is to mitigate these risks.

And let us be clear, when we speak of potentially catastrophic consequences in this context, we are talking about the devastating impacts on ecosystems and biodiversity, severe flood damage to urban centers and island nations as sea level rises, significantly more destructive and frequent extreme weather events, such as droughts and floods, seriously affected agricultural productivity in many countries, exacerbation of certain diseases, population dislocations and so, on and on.

A reasonable target, in my view, is to attempt to limit the global temperature increase to less than, say, four degrees Fahrenheit. Recent estimates indicate that stabilizing the amount of greenhouse gases in the atmosphere at the equivalent of twice the preindustrial value of 280 parts per million of carbon dioxide, this provides only a 10 to 20 percent chance of limiting global average temperature rise to four degrees Fahrenheit.

Put another way, this means that the odds that average global temperature will rise above four degrees is 80 to 90 percent. Unless society starts taking some aggressive actions now, we are well on our way to reaching perhaps even a tripling of pre-industrial carbon dioxide levels with far greater adverse economic and environmental consequences.

The CHAIRMAN. Doctor, I hate to tell you this, but you better——

Dr. MOLINA. Okay.

The CHAIRMAN. Maybe two more minutes.

Dr. MOLINA. Two more—I will. I applaud the committee for its commitment to explore proposals consistent with the sense of the Senate resolution. And moreover, I commend you for beginning this exploration with a discussion of climate change. As you know, I am one of sixteen members of the National Commission on Energy Policy, and you will hear more about the Commission from Jason Grumet, our executive director. But one of my main contributions to the Commission's deliberations was helping the group understand the challenge of forging sound climate change in the face of evolving scientific knowledge.

This national commission agreed on some statements, which I will end my testimony just summarizing this consensus from this group, which you will hear more about. I quote, "We understand that the scientific consensus has emerged that global temperatures have been increasing at the rate that is outside the range of natural variability. Continuation of the greenhouse gas emission trends along business-as-usual lines could produce changes in climatic patterns in this century that will produce significant adverse impacts on human societies."

The second point. "There are many uncertainties in the details of the timing and severity of the changes in climates; economic, environmental, and social impacts of these changes as well that will result if business as usual prevails. There are also uncertainties about the availability and costs of energy supply and energy-induced technologies that might be brought to bear to achieve much lower greenhouse emissions than those expected with business as usual."

"But these uncertainties for further research and development to try to reduce them, they are not proper cause for taking no other action to reduce the risks from human-caused climate change. What is already known about this risk is sufficient reason to accelerate, starting now, the search for a mix of affordable technical and policy measures that will be able to reduce greenhouse emissions substantially, furthermore to adapt to the degree of climate change that cannot be avoided without incurring unreasonable costs. This is not only a major challenge in fashioning a sensible energy policy for the United States, but it is a challenge that no sensible energy policy can ignore."

I thank you for your attention and look forward to working with the committee in the weeks and months ahead.

The CHAIRMAN. Thank you very much.

[The prepared statement of Dr. Molina follows:]

PREPARED STATEMENT OF PROFESSOR MARIO MOLINA, UNIVERSITY OF CALIFORNIA, SAN DIEGO

Good Morning. I am very pleased to be here to discuss the science of climate change and to reflect on the very real challenge of making sound policy choices in the face of uncertainty. Climate change is perhaps the most worrisome global environmental problem confronting human society today. It involves a complex interplay of scientific, economic, and political issues. The impacts of climate change are potentially very large and will occur over a time scale of decades to centuries. The actions needed to respond to this challenge require substantial long-term commitments to change traditional economic development paths throughout the world. The ultimate solution to the challenge will require a fundamental transformation in the production and consumption of energy here in the United States and by developed and developing nations alike.

I want to address the bulk of my remarks to the threshold question: Do we know enough about climate change to act now and to start doing something serious to address this problem? Let me first comment on what I think the role of scientists should be in answering this question. Ultimately policy decisions about climate change have to be made by society at large, and more specifically by policymakers. Scientists do not have any special privilege to make such decisions, but science does play a fundamental role on this issue. The climate system is very complicated and science does not have all the answers: there are uncertainties in predicting when and to what extent will the climate change as a consequence of a given course of human activities. However, scientists can estimate the probability that the earth's climate will respond in certain ways. For simplicity the climate response is often represented as the increase in average global surface temperature of the planet say, by the end of the century. This information can be used by policymakers to assess the risks imposed by climate change and to device adequate responses to address the challenge.

Let me begin by simply summarizing what we know about climate change. I firmly embrace the view expressed in the recent Sense of the Senate Resolution that "there is a growing scientific consensus that human activity is a substantial cause of greenhouse gas accumulation in the atmosphere, and that these accumulating gasses are causing average temperatures to rise at a rate outside of natural variability."

Simply stated, the world is warming.

- It is due to our emissions.
- More warming is inevitable—but the amount of future warming is in our hands.
- Because CO_2 accumulates and remains in the atmosphere, each generation inherits the emissions of all those who have gone before. Many future generations of human beings will wrestle with this issue.

- Modest amounts of warming will have both positive and negative impacts. But above a certain threshold, the impacts turn strongly negative for most nations, people, and biological systems.

While there is a growing scientific consensus around the science of climate change, there is of course much that we do not fully understand about the timing, geographic distribution, and severity of the changes in climate—and the economic, environmental, and social impacts of these changes—that will result if heat-forcing emissions continue to increase. However, not knowing with certainty how the climate system will respond should not be an excuse for inaction. Policymakers are frequently, indeed usually, in the position of making decisions in the face of uncertainties. Usually, the presence of uncertainty means that we build in extra insurance to protect against the risk that consequences may be worse than we expect. It would be better, of course, if we knew exactly where the perfect balance between cost, risk, and benefit lies. But the fact is that we never have that luxury. Nevertheless, policy makers and individuals both must manage public and personal risks all the time and we do. Most people buy car insurance even though they don't know with any degree of certainty what their individual risk of being in a car accident might be, just as most doctors would advise an individual with a history of heart trouble to choose low-fat foods and exercise despite the many complex and usually unknowable factors that go into determining any individual person's risk of having a heart attack.

If we apply the same logic in setting goals for limiting the risks associated with future climate change, it becomes very clear that our current course now places us far outside the kinds of risk thresholds we typically apply in other areas of public policy. Put another way, there is now an overwhelming consensus that failure to limit greenhouse gas emissions will produce a risk of significant adverse consequences that is far higher than we find acceptable in other arenas. When facing a substantial chance of potentially catastrophic consequences and the near certainty of lesser negative effects, the only prudent course of action is to mitigate these risks. And let us be clear—when we speak of potentially catastrophic consequences in this context we are talking about devastating impacts on ecosystems and biodiversity; severe flood damage to urban centers and island nations as sea level rises; significantly more destructive and frequent extreme weather events such as droughts and floods; seriously affected agricultural productivity in many countries; the exacerbation of certain diseases; population dislocations; etc.

A reasonable target, in my view, is to attempt to limit the global temperature increase to less than about 4 degrees Fahrenheit. Recent estimates indicate that stabilizing the amount of greenhouse gases in the atmosphere at the equivalent of twice the pre-industrial value of 280 ppm carbon dioxide provides only a 10-20 per cent chance of limiting global average temperature rise to 4 degrees Fahrenheit. Put another way, this means that the odds that average global temperatures will rise above 4 degrees is 80 to 90 percent. Unless society starts taking some aggressive actions now, we are well on our way to reaching perhaps even a tripling of pre-industrial carbon dioxide levels with far greater adverse economic and environmental consequences.

The risks to human society and ecosystems grow significantly if the average global surface temperature increases 5 degrees Fahrenheit or more. Such a large temperature increase might entail, for example, substantial agricultural losses, widespread adverse health impacts and greatly increased risks of water shortages. Furthermore, a very high proportion of the world's coral reefs would be imperiled and many terrestrial ecosystems could suffer irreversible damage. The risk of runaway or abrupt climate change also increases rapidly if the average temperature increases above about 5 degrees Fahrenheit. It is possible, for example, that the West Antarctic and Greenland ice sheets will melt, raising sea levels more than ten meters over the period of a few centuries. It is also possible that the ocean circulation will change abruptly, perhaps shutting down the Gulf Stream.

I applaud the Committee for its commitment to explore legislative proposals consistent with the Sense of the Senate Resolution and moreover commend you for beginning this exploration with a discussion of climate science. As you may know, I am one of sixteen members of the National Commission for Energy Policy (NCEP). You will hear more about the Commission from Jason Grumet, our Executive Director, shortly. One of my main contributions to the Commission's deliberations was helping the group understand the challenge of forging sound climate policy in the face of evolving scientific knowledge. Early on in our deliberations we agreed upon the following brief statement to guide our policy exploration. I offer it here for the Committee's deliberations:

"(1) We understand that a scientific consensus has emerged that (a) global temperatures have been increasing at a rate that is outside the range of natural variability, (b) human emissions of CO_2 and other greenhouse gases have been responsible for a part of this increase, and (c) continuation of these emission trends along "business as usual" lines could produce changes in climatic patterns in this century that will produce significant adverse impacts on human societies.

(2) There are many uncertainties in the details of the timing, geographic distribution, and severity of the changes in climate—and the economic, environmental, and social impacts of these changes—that will result if "business as usual" prevails. There are, likewise, significant uncertainties about the availability and costs of energy-supply and energy-end-use technologies that might be brought to bear to achieve much lower greenhouse-gas emissions than those expected on the "business as usual" trajectory.

(3) These uncertainties are cause for further research and development to try to reduce them, but they are not proper cause for taking no other action to reduce the risks from human-caused climate change. What is already known about these risks is sufficient reason to accelerate, starting now, the search for a mix of affordable technical and policy measures that will be able (a) to reduce greenhouse-gas emissions substantially from the "business as usual" trajectory in the aggregate over a relevant time frame, and (b) to adapt to the degree of climate change that cannot be avoided without incurring unreasonable costs. This is not the only major challenge in fashioning a sensible energy policy for the United States, but it is a challenge that no sensible energy policy can ignore."

I thank you for your attention and look forward to working with the Committee in the weeks and months ahead.

The CHAIRMAN. You may proceed, Doctor.

STATEMENT OF JAMES W. HURRELL, PH.D., DIRECTOR, CLIMATE AND GLOBAL DYNAMICS DIVISION, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH, BOULDER, CO

Dr. HURRELL. I thank Chairman Domenici, Ranking Member Bingaman, and the other members of the committee for the opportunity to speak with you today on the science of global climate change. It is a privilege to be here. My name is Jim Hurrell, and I am director of the Climate and Global Dynamics Division at the National Center for Atmospheric Research in Boulder, Colorado.

There will always be uncertainty in understanding the causes and the processes of climate variability and climate change, simply because the climate system is an extremely complex, non-linear system. However, significant advances in the scientific understanding of climate change now make it clear that there has been a change in climate that goes beyond the range of natural variability.

The globe is warming at a dramatic rate, and any claims to the contrary are not credible. Global surface temperatures today are more than one degree Fahrenheit warmer than at the beginning of the 20th century. And the rates of temperature rise are greatest in recent decades.

Nine of the last 10 years are among the warmest 10 years in the instrumental record, which dates back to about 1860. Based on reconstructions of temperature from proxy data like tree rings and ice cores, several studies have concluded that northern hemisphere surface temperatures are warmer now than at any other time in at least the last 1,000 years.

The surface warming is consistent with a body of other observations that gives a consistent picture of a warming world. For example, there has been a widespread reduction in the number of frost days in middle latitude regions. And there has been an increase in the number of warm extremes. Ocean temperatures have warmed, and global sea levels have risen 15 to 20 centimeters over the 20th century, as a result. Snow cover has decreased in many regions and sea-ice extents have decreased in the Arctic. There has been a nearly worldwide reduction in mountain glacier mass and extent.

Because today's best climate models are now able to reproduce the climate of the past century, they are very useful tools for understanding and determining the changes in forcing that have driven this observed warming. Forcings imposed on the climate system can be natural in origin, such as changes in solar luminosity or volcanic eruptions, or they can be human induced, such as the buildup of greenhouse gas concentrations in the atmosphere.

Greenhouse gas concentrations in the atmosphere are now higher than at any time in at least the last 750,000 years. In the absence of controls, future projections are that the rate of increase in carbon dioxide may accelerate and concentrations could double from pre-industrial values within the next 50 to 100 years.

Climate model simulations that account for such changes in climate forcings have now reliably shown that global surface warming of recent decades is a response to the increased concentrations of greenhouse gases. Moreover, this attribution of the recent climate change has direct implications for the future. Because of the very long lifetime of carbon dioxide in the atmosphere, there is a substantial future commitment to further global change, even in the absence of further increases and emissions.

In summary, the scientific understanding of climate change is now sufficiently clear to show that climate change from global warming is already upon us. Uncertainties remain, especially regarding how climate will change at regional and local scales. But the climate is changing, and the rate of change, as projected, exceeds anything seen in nature in the past 10,000 years.

Mitigation actions taken now to decrease concentrations of greenhouse gases in the atmosphere mainly have benefits 50 years from now and beyond. There is no quick fix. While some changes might be benign or even beneficial in some geographical areas, global warming will be disruptive in many ways.

Hence, it is vital to plan to cope with the changes, such as enhanced drought, heat waves, wildland fires, and flooding. The science of global climate change is certainly sophisticated enough at this point to help policymakers make real decisions now that will benefit the planet in the future.

Again, I sincerely thank you for the opportunity to address this committee.

The CHAIRMAN. Thank you very much.

[The prepared statement of Dr. Hurrell follows:]

PREPARED STATEMENT OF JAMES W. HURRELL, PH.D., DIRECTOR, CLIMATE AND GLOBAL DYNAMICS DIVISION NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

INTRODUCTION

I thank Chairman Domenici, Ranking Member Bingaman, and the other Members of the Committee for the opportunity to speak with you today on the science of global climate change. My name is James W. Hurrell, Director of the Climate and Global Dynamics Division (CGD) at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado. My personal research has centered on empirical and modeling studies and diagnostic analyses to better understand climate, climate variability and climate change. I have authored or co-authored more than 60 peer-reviewed scientific journal articles and book chapters, as well as dozens of other planning documents and workshop papers. I have given more than 65 invited talks worldwide, as well as many contributed presentations at national and international conferences on climate. I have also convened over one dozen national and international workshops, and I have served on several national and international science-planning efforts. Currently, I am extensively involved in the World Climate Research Programme (WCRP) on Climate Variability and Predictability (CLIVAR), and I serve as co-chair of Scientific Steering Committee of U.S. CLIVAR. I have also been involved in the assessment activities of the Intergovernmental Panel on Climate Change (IPCC) as a contributing author to chapters in both the third and fourth (in progress) assessment reports, and I have served on several National Research Council (NRC) panels. I am also a lead author on the U.S. Climate Change Science Program's (CCSP) Synthesis and Assessment Product on Temperature Trends in the Lower Atmosphere.

Throughout this testimony I will refer to both the IPCC and the CCSP. Briefly, the IPCC is a body of scientists from around the world convened by the United Nations jointly under the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). Its mandate is to provide policy makers with an objective assessment of the scientific and technical information available about climate change, its environmental and socio-economic impacts, and possible response options. The IPCC reports on the science of global climate change and the effects of human activities on climate in particular. The fourth major assessment is underway (the previous assessments were published in 1990, 1995 and 2001) and is due to be published in 2007. Each new IPCC report reviews all the published literature over the previous 5 years or so, and assesses the state of knowledge, while trying to reconcile disparate claims, resolve discrepancies and document uncertainties. For the 2001 Third Assessment Report (TAR), Working Group I (which deals with how the climate has changed and the possible causes) consisted of 123 lead authors, 516 contributors, 21 review editors, and over 700 reviewers. It is a very open process. The TAR concluded that climate is changing in ways that cannot be accounted for by natural variability and that "global warming" is happening.

The U.S. CCSP was established in 2002 to coordinate climate and global change research conducted in the United States. Building on and incorporating the U.S. Global Change Research Program of the previous decade, the program integrates federal research on climate and global change, as sponsored by 13 federal agencies and overseen by the Office of Science and Technology Policy, the Council on Environmental Quality, the National Economic Council and the Office of Management and Budget. A primary objective of the CCSP is to provide the best possible scientific information to support public discussion and government and private sector decision-making on key climate-related issues. To help meet this objective, the CCSP is producing a series of synthesis and assessment products that address its highest priority research, observation, and decision-support needs. Each of these products will be written by a team of authors selected on the basis of their past record of interest and accomplishment in the given topic. The Product on Temperature Trends in the Lower Atmosphere focuses on both understanding reported differences between independently produced data sets of temperature trends for the surface through the lower stratosphere and comparing these data sets to model simulations.

OBSERVED CLIMATE CHANGE

a. Surface Temperature

Improvements have been made to both land surface air temperature and sea surface temperature (SST) data during the five years since the TAR was published. The improvements relate to improved coverage, particularly over the Southern Hemisphere (SH) in the late 19th century, and daily temperature data for an increasing number of land stations have also become available, allowing more detailed assessment of extremes, as well as potential urban influences on both large-scale temperature averages and microclimate.

The globe is warming. Claims to the contrary are not credible. Three different analyses of observations of surface temperature averaged across the globe show a linear warming trend of 0.6° C ±0.2° C since the beginning of the 20th century. Rates of temperature rise are greater in recent decades: since 1979, global surface temperatures have increased more than 0.4° C. Land regions have warmed the most (0.7° C since 1979), with the greatest warming in the boreal winter and spring months over the Northern Hemisphere (NH) continents. A number of recent studies indicate that effects of urbanization and land-use change on the land-based temperature record are negligible as far as continental-and hemispheric-space averages are concerned, because the very real but local effects are accounted for. Recent warming is strongly evident at all latitudes over each of the ocean basins and, averaged over the globe, the SSTs have warmed 0.35° C since 1979. The trends over the past 25 years have been fairly linear; however the global temperature changes over the entire instrumental record are best described by relatively steady temperatures from 1861-1920, a warming of about 0.3° C to 1950, a cooling of about 0.1° C until the mid-1970s, and a warming of about 0.55° C since then. Thus, global surface temperatures today are about 0.75° C warmer than at the beginning of the 20th century.

The warmest year in the 145-year global instrumental record remains 1998, since the major 1997-98 El Niño enhanced it. The years 2002-2004 are the 2nd, 3rd and 4th warmest years in the series since 1861 and nine of the last 10 years (1995 to 2004)—the exception being 1996—are among the ten warmest years in the instrumental record. Based on reconstructions of temperature from proxy data, like tree rings and ice cores, several studies have also concluded that NH surface temperatures are warmer now than at any time in at least the last 1,000 years.

b. Consistency with other observed changes

The warming described above is consistent with a body of other observations that gives a consistent picture of a warming world. For example, there has been a widespread reduction in the number of frost days in middle latitude regions, principally due to an earlier last day of frost in spring rather than a later start to the frost season in autumn. There has been an increase in the number of warm extremes and a reduction in the number of daily cold extremes, especially at night. The amount of water vapor in the atmosphere has increased over the global oceans by 1.2 ±0.3% from 1988 to 2004, consistent in patterns and amount with changes in SST and a fairly constant relative humidity. Widespread increases in surface water vapor are also found. Ocean temperatures have warmed at depth as well, and global sea levels have risen 15-20 centimeters over the 20th century: as the oceans warm, seawater expands and sea level rises.

There has been a nearly worldwide reduction in mountain glacier mass and extent. Snow cover has decreased in many NH regions, particularly in the spring season and this is consistent with greater increases in spring than autumn surface temperatures in middle latitude regions. Sea-ice extents have decreased in the Arctic, particularly in the spring and summer seasons, and patterns of the changes are consistent with regions showing a temperature increase. The Arctic (north of 65°N) average annual temperature has increased since the 1960s and is now warmer (at the decade timescale) than conditions experienced during the 1920-1945 period (where much of the earlier global warming was centered). In the Antarctic, there are regional patterns of warming and cooling related to changes in the atmospheric circulation. The warming of the Peninsula region since the early 1950s is one the largest and the most consistent warming signals observed anywhere in the world. Large reductions in sea-ice have occurred to the west in the Bellingshausen Sea, and on the eastern side of Peninsula, large reductions in the size of Larsen Ice shelf have occurred.

c. Temperature of the Upper Air

Radiosonde releases provide the longest record of upper-air measurements, and these data show similar warming rates to the surface temperature record since 1958. Unfortunately, however, vast regions of the oceans and portions of the landmasses (especially in the Tropics) are not monitored so that there is always a component of the global or hemispheric mean temperature that is missing. Moreover, like all measurement systems, radiosonde records of temperature have inherent uncertainties associated with the instruments employed and with changes in instrumentation and observing practices, among other factors.

Fundamentally, these uncertainties arise because the primary purpose of radiosondes is to help forecast the weather, not monitor climate variability and change. Therefore, all climate data sets require careful examination for instrument biases and reliability (quality control) and to remove changes that might have arisen for non-climatic reasons (a process called "homogenization") It is difficult to remove all non-climatic effects, and ideally multiple data sets should be produced independently to see how sensitive results are to homogenization choices. This has been the case for the surface record, but unfortunately much less so for the radiosonde record (although efforts are increasing.)

For this reason, much attention has been paid to satellite estimates of upper-air temperatures, in particular because they provide true global coverage. Of special interest have been estimates of tropospheric and stratospheric temperatures over thick atmospheric layers obtained from microwave sounding units (MSU) onboard NOAA polar-orbiting satellites since 1979. Initial analyses of the MSU data by scientists at the University of Alabama, Huntsville (UAH) indicated that temperatures in the troposphere showed little or no warming, in stark contrast with surface air measurements. Climate change skeptics have used this result to raise questions about both the reliability of the surface record and the cause of the surface warming, since human influences thought to be important are expected to increase temperatures both at the surface and in the troposphere. They also have used the satellite record to caste doubt on the utility of climate models, which simulate both surface and tropospheric warming in over recent decades.

In an attempt to resolve these issues, the NRC in 2000 studied the problem and concluded that "the warming trend in global-mean surface temperature observations during the past 20 years is undoubtedly real and is substantially greater than the average rate of warming during the 20th century. The disparity between surface and upper air trends in no way invalidates the conclusion that surface temperature has been rising." The NRC further found that corrections in the MSU processing algorithms brought the satellite data record into slightly closer alignment with surface temperature trends, but substantial discrepancies remained. As further noted by the TAR, some, but not all, of these remaining discrepancies could be attributed to the fact that the surface and the troposphere respond differently to climate forcings, so that trends over a decade or two should not necessarily be expected to agree.

Since the IPCC and NRC assessments, new data sets and modeling simulations have become available which are helping to resolve this apparent dilemma. The CCSP Assessment Product on *Temperature Trends in the Lower Atmosphere* is assessing these new data, and the preliminary report (which has been reviewed by the NRC) finds that the surface and upper-air records of temperature change can now, in fact, be reconciled. Moreover, the overall pattern of observed temperature change in the vertical is consistent with that simulated by today's climate models.

Several developments since the TAR are especially notable:

- A second, independent record of MSU temperatures has become available from scientists at the Remote Sensing Systems (RSS) Laboratory. Although both the UAH and RSS groups start from the same raw radiance data, they apply different construction methods of merging the MSU data from one satellite to the next. The result is that, while both data sets indicate the middle troposphere has warmed since 1979, the RSS estimate is approximately 0.1° C decade^{-1} warmer than the UAH estimate. Moreover, the RSS trend is not statistically different from the observed surface warming since 1979. The difference in tropospheric temperature trends between these two products highlights the issue of temporal homogeneity in the satellite data.
- Both UAH and RSS MSU products support the conclusion that the stratosphere has undergone strong cooling since 1979, due to observed stratospheric ozone depletion.
- Because about 15% of the MSU signal for middle tropospheric temperature actually comes from the lower stratosphere, the real warming of the middle troposphere is greater than that indicated by the MSU data sets. This has been confirmed by new analyses that explicitly remove the stratospheric influence, which is about $-0.08°$ C decade^{-1} on middle tropospheric MSU temperature trends since 1979.
- By differencing MSU measurements made at different slant angles, both the UAH and the RSS groups have produced updated data records weighted more toward the lower troposphere. The RSS product exhibits a warming trend that is 0.2° C decade^{-1} larger than that from UAH. In part, this discrepancy is because adjustments for diurnal cycle corrections required from satellite drift had the wrong sign in the UAH record. As a result, a new UAH record is being prepared, and the current version is regarded as obsolete.

The various new data sets of upper-air temperature are very important because their differences highlight differences in construction methodologies. It therefore becomes possible to estimate the uncertainty in satellite-derived temperature trends that arises from different methods.

d. Extremes

For any change in mean climate, there is likely to be an amplified change in extremes. The wide range of natural variability associated with day-to-day weather means that we are unlikely to notice most small climate changes except for changes in the occurrence of extremes. Extreme events, such as heat waves, floods and droughts, are exceedingly important to both natural systems and human systems and infrastructure. We are adapted to a range of natural weather variations, but it is the extremes of weather and climate that exceed tolerances.

In several regions of the world indications of a change in various types of extreme weather and climate events have been found. So far, the most prominent indication of a change in extremes is the evidence of increases in moderate to heavy precipitation events over the middle latitudes in the last 50 years, even for regions where annual precipitation totals are decreasing. Further indications of a robust change include the observed trend to fewer frost days associated with the average warming in most middle latitude regions. Results for temperature-related daily extremes are also relatively coherent for some measures. Many regions show increased numbers of warm days/nights (and lengthening of heat waves) and even more reductions in the number of cold days/nights, but changes are not ubiquitous.

Trends in tropical storm frequency and intensity are masked by large natural variability on multiple timescales. Increases may be occurring in recent years, but apart from the North Atlantic basin, most measures only begin in the 1950s or 1960s and have likely missed some events in the early decades. Numbers of hurricanes in the North Atlantic have been above normal in 8 of the last 10 years, but levels were about as high in the 1950s and 1960s. This pattern continues this summer, with a very active hurricane season already evident and SSTs at record high levels.

MODELING AND ATTRIBUTION OF CLIMATE CHANGE

a. Improved simulations of past climate

The best climate models encapsulate the current understanding of the physical processes involved in the climate system, the interactions, and the performance of the system as a whole. They have been extensively tested and evaluated using observations. They are exceedingly useful tools for carrying out numerical climate experiments, but they are not perfect, and some models are better than others. Uncertainties arise from shortcomings in our understanding of climate processes operating in the atmosphere, ocean, land and cryosphere, and how to best represent those processes in models. Yet, in spite of these uncertainties, today's best climate models are now able to reproduce the climate of the past century, and simulations of the evolution of global surface temperature over the past millennium are consistent with paleoclimate reconstructions.

As a result, climate modelers are able to test the role of various forcings in producing the observed changes in global temperature temperatures. Forcings imposed on the climate system can be natural in origin, such as changes in solar luminosity or volcanic eruptions, the latter adding considerable amounts of aerosol to the upper atmosphere for up to two years. Human activities also increase aerosol concentrations in the atmosphere, mainly through the injection of sulfur dioxide from power stations and through biomass burning. A direct effect of sulfate aerosols is the reflection of a fraction of solar radiation back to space, which tends to cool the Earth's surface. Other aerosols (like soot) directly absorb solar radiation leading to local heating of the atmosphere, and some absorb and emit infrared radiation. A further influence of aerosols is that many act as nuclei on which cloud droplets condense, affecting the number and size of droplets in a cloud and hence altering the reflection and the absorption of solar radiation by the cloud. The precise nature of aerosol/cloud interactions and how they interact with the water cycle remains a major uncertainty in our understanding of climate processes. Because man-made aerosols are mostly introduced near the Earth's surface, they can be washed out of the atmosphere by rain. They therefore typically remain in the atmosphere for only a few days, and they tend to be concentrated near their sources such as industrial regions. Therefore, they affect climate with a very strong regional pattern and usually produce cooling.

In contrast, greenhouse gases such as carbon dioxide and methane are not washed out, so they have lifetimes of decades or longer. As a result, they build up in amounts over time, as has been observed. Greenhouse gas concentrations in the atmosphere are now higher than at any time in at least the last 750,000 years. It took at least 10,000 years from the end of the last ice age for levels of carbon dioxide to increase 100 parts per million by volume (ppmv) to 280 ppmv, but that same increase has occurred over only the past 150 years to current values of over 370 ppmv. About half of that increase has occurred over the last 35 years, owing mainly to combustion of fossil fuels and deforestation. In the absence of controls, future projections are that the rate of increase in carbon dioxide amount may accelerate, and concentrations could double from pre-industrial values within the next 50 to 100 years.

Climate model simulations that account for such changes in forcings have now reliably shown that global surface warming of recent decades is a response to the increased concentrations of greenhouse gases and sulfate aerosols in the atmosphere. When the models are run without these forcing changes, they fail to capture the almost linear increase in global surface temperatures since the mid-1970s. But when the anthropogenic forcings are included, the models simulate the observed temperature record with impressive fidelity. These same model experiments also reveal that changes in solar luminosity account for much of the warming in the first half of the 20th century. Such results increase our confidence in the observational record and our understanding of how temperature has changed. They also mean that the time histories of the important forcings are reasonably known, and that the processes being simulated models are adequate enough to make the models very valuable tools.

b. Commitment to further climate change

The ability of climate models to simulate the past climate record gives us increased confidence in their ability to simulate the future. Moreover, the attribution of the recent climate change to increased concentrations of greenhouse gases in the atmosphere has direct implications for the future. Because of the long lifetime of carbon dioxide and the slow equilibration of the oceans, there is a substantial future commitment to further global climate change even in the absence of further emissions of greenhouse gases into the atmosphere. Several modeling groups have performed "commitment" runs in order to examine the climate response even if the concentrations of greenhouse gases in the atmosphere had been stabilized in the year 2000. The exact results depend upon the model, but they all show a further global warming of about another 0.5° C, and additional and significant sea level rises caused by thermal expansion of the oceans by the end of the 21st century. Further glacial melt is also likely.

The climate modeling groups contributing to the Fourth IPCC Assessment Report have produced the most extensive internationally coordinated climate change experiment ever performed (21 global coupled models from 14 countries). This has allowed better quantification of multi-model responses to three scenarios of 21st century climate corresponding to low (550 ppmv), medium (690 ppmv) and high (820 ppmv) increases of carbon dioxide concentrations by the year 2100. In spite of differences among models and the uncertainties that exist, the models produce some consistent results:

- Over the next decade or two, all models produce similar warming trends in global surface temperatures, regardless of the scenario.
- Nearly half of the early 21st century climate change arises from warming we are already committed to. By mid-century, the choice of scenario becomes more important for the magnitude of warming, and by the end of the 21st century there are clear consequences for which scenario is followed.
- The pattern of warming in the atmosphere, with a maximum in the upper tropical troposphere and cooling in the stratosphere, becomes established early in this century.
- Geographical patterns of warming show greatest temperature increases at high northern latitudes and over land, with less warming over the southern oceans and North Atlantic. In spite of a slowdown of the meridional overturning circulation and changes in the Gulf Stream in the ocean across models, there is still warming over the North Atlantic and Europe due to the overwhelming effects of the increased concentrations of greenhouse gases.
- Precipitation generally increases in the summer monsoons and over the tropical Pacific in particular, with general decreases in the subtropics and some middle latitude areas, and increases at high latitudes.

c. Increasing complexity of models

As our knowledge of the different components of the climate system and their interactions increases, so does the complexity of climate models. Historical changes in land use and changes in the distribution of continental water due to dams and irrigation, for instance, need to be considered. Future projected land cover changes due to human land uses are also likely to significantly affect climate, and these effects are only now being included in climate models.

One of the major advances in climate modeling in recent years has been the introduction of coupled climate-carbon models. Climate change is expected to influence the capacities of the land and oceans to act as repositories for anthropogenic carbon dioxide, and hence provide a feedback to climate change. These models now allow us to assess the nature of this feedback. Results show that carbon sink strengths are inversely related to the rate of fossil fuel emissions, so that carbon storage capacities of the land and oceans decrease and climate warming accelerates with faster carbon dioxide emissions. Furthermore, there is a positive feedback between the carbon and climate systems, so that further warming acts to increase the airborne fraction of anthropogenic carbon dioxide and amplify the climate change itself.

POLICY IMPLICATIONS

In summary, the scientific understanding of climate change is now sufficiently clear to show that climate change from global warming is already upon us. Uncertainties remain, especially regarding how climate will change at regional and local scales. But the climate is changing and the uncertainties make the need for action all the more imperative. At the same time, it should be recognized that mitigation actions taken now mainly have benefits 50 years and beyond now. This also means that we will have to adapt to climate change by planning for it and making better predictions of likely outcomes on several time horizons. My personal view it that it is vital that all nations identify cost-effective steps that they can take now, to contribute to substantial and long-term reductions in net global greenhouse gas emissions. Action taken now to reduce significantly the build-up of greenhouse gases in the atmosphere will lessen the magnitude and rate of climate change. While some changes arising from global warming are benign or even beneficial, the rate of change as projected exceeds anything seen in nature in the past 10,000 years. It is apt to be disruptive in many ways. Hence it is also vital to plan to cope with the changes, such as enhanced droughts, heat waves and wild fires, and stronger downpours and risk of flooding. Managing water resources will be major challenge in the future.

Again, I appreciate the opportunity to address the Committee concerning the science of global climate change—a topic that is of the utmost importance for the future of our planet.

The CHAIRMAN. And thanks to all of you. Now let us see if we have enough Senators. Do we?

[Whereupon, a business meeting was held from 10:47 a.m. to 10:49 a.m.]

The CHAIRMAN. Now we are going to proceed. We have one set of panels—or one panel after this. We want to get them up before noon. But we really do want every Senator that wants to to ask questions.

I am going to start with you, Senator Bingaman, then with you, Senator Craig, and go right down the line.

Senator Bingaman.

Senator BINGAMAN. Well, thank you very much, Mr. Chairman. One of the issues that I think several of you alluded to that I think is important to focus on here is the length of time that gases that we emit today remain in the atmosphere, and the fact that by continuing to add to the greenhouse gases, we buildup a store that takes decades and even centuries to settle back out. I guess that is what eventually happens to the greenhouse gases in the atmosphere, although I am not sure of that.

Maybe Dr. Hurrell, you could address that, and anybody else who had a comment as to what the science tells us about the length of time that these gases are going to remain there and continue to cause increasing temperatures.

Dr. HURRELL. You are correct, Senator Bingaman. The lifetime of greenhouse gases in the atmosphere is on the time scale of decades to centuries. And so the buildup of greenhouse gases in the atmosphere continues to accumulate over time. And so some of the experiments, in terms of the impacts that we do with climate models, some new types of experiments, are what we call commitment runs.

For instance, if emissions were capped at today's levels, what would happen in the future because of the continued buildup of greenhouse gas concentrations in the atmosphere? And those climate model simulations do indicate that there will be a continued increase in global surface temperatures that we are already committed to. Something on the order of approaching another degree Fahrenheit over the next 50 years. And sea levels will continue to rise as well.

Senator BINGAMAN. All right. Dr. Cicerone, did you have any comment on that?

Dr. CICERONE. Yes, Senator Bingaman. Carbon dioxide is clearly the most important human-caused greenhouse gas, and I agree completely with what Dr. Hurrell said. The other greenhouse gas is methane, which has a residence time of 10 or 12 years. So that it is much more susceptible to short-term changes and to our increasing the emissions or decreasing the emissions. We should see changes in methane more quickly.

Nitrous oxide, 150 years. There are some exotic chemicals, which although present in much smaller amounts, survive for tens of thousands of years. Sulfurhexaflouride and some pro-fluorinated hydrocarbons, which were produced inadvertently by the aluminum industry, which I think has been somewhat successful in eliminating those emissions. So there is a spectrum.

One of the greenhouse gases is much shorter lived. It is ozone produced in ground-level air pollution. Chemistry reactions may survive only a couple hundred days. But the principal one is exactly as Dr. Hurrell said.

Senator BINGAMAN. Let me ask one other question. All the discussion so far this morning that I have been listening to relates to incremental changes in climate that we can anticipate if we continue to emit the level of greenhouse gases we are currently emitting, or the amounts we are expected to emit in the future.

What could you tell us about the issue of abrupt climate change? This is something that I hear about and how does this relate to what the testimony that you have given on this other issue?

Sir HOUGHTON. Maybe I should have a go at that. Climate is a very non-linear system, so that you may go along without too much change, then all of a sudden something happens, because a threshold or something has been reached. We do not know of any very tight thresholds, but we do know that certain things are happening which could lead to very large effects. And one of those is the meltdown of Greenland, for instance, a certain threshold. Greenland is in balance at the moment, roughly speaking, between a glacier on the outside, and accumulation in the middle.

Now if that starts to change rapidly, then Greenland will begin to melt down. It will maybe take a thousand years or more, but there is seven meters of sea level which lies within Greenland.

Furthermore, which, of course, has been well publicized in that film, "The Day After Tomorrow"—you need not believe all of it, by any means. You need not believe the speculative events which occurred afterwards. But the signs on which it is predicated is the weakening of the Gulf Stream. And all the climate models, the coupled ocean atmosphere climate models that couple the two circulations together, show this effect.

As you freshen the water in the higher latitudes, because of increased precipitation or because of melting ice, then this stops the water in the ocean becoming so salty. It becomes less dense, and therefore, it does not sink to the bottom and start to form the deep ocean circulation, which circulates between all the oceans. And what happens is that that then weakens the whole of the Gulf Stream circulation and will have profound impacts on the weather, particularly of Western Europe, but not as severe, on the whole globe.

As I say, all climate models show that weakening, while a few of them show it cutting it off after a few hundred years or so. There is still a lot of debate about the timing of that. But the fact that that could occur is really very, very well understood now, and probably will occur in the future.

There is also the breakdown of the West Antarctic ice sheet, which is another possible threshold. There are other things, like release of methane from sources in the deep oceans or in the ice. That is the further one which we are concerned about, but the evidence of that is not too strong. But all these things are there in the wings, or in the possibilities, which we shall be aware of even if we are concentrating on the things we are more sure about.

Dr. MOLINA. Can I add something to that? I just want to point out that the risks to human society of these abrupt changes increase rapidly as the amount of greenhouse gases in the atmosphere increases. It is very non-linear. But, to put it in simple terms, if we double the amount of greenhouse gases in the atmosphere, the risk does not double. Perhaps it quadruples or perhaps it increases even a factor of ten. So we have a very non-linear response. We get into a very dangerous situation as we increase the amount of these gases.

Senator BINGAMAN. Thank you, Mr. Chairman.

Senator CRAIG. Let me thank all of you for being here. I have read many of your works and a lot of the publications over the last decade and have been fully engaged in this issue, both as an observer and sometimes a critic. But I have grown to believe, as many of my colleagues have, that there is a substantial human effect on the environment. And you have outlined that in a variety of ways this morning.

My responsibility is best I can, is to question the science, but at the same time, as the science seems to confirm human activity as a major contributor. Climate variability is something that I think we are all very willing to look at and see as a part of it. So it is very important for us, as policymakers, to insist that you all get it right as best science can.

Having said that, let me revert back to where I think I and others on this committee play the role, and that is in the policy formed and how we get there. Many of you have said that no matter what we do, this very big world of ours is a ship that turns with great slowness. And I am extremely concerned, in a positive/negative way, about the growth of emerging economies and their contribution, and what we can do not only for ourselves, but with them and for them.

Abrupt changes in our approach toward adjusting create consequences. And, therefore, technologies are extremely important, I think. Clean technologies, in not only moving us in the right direction, but moving the world in the right direction, because this great

Nation of ours makes almost everything that we produce available to the rest of the world. And we have that tremendous capacity. We just produced legislation that I think is of substantially greater significance to climate change than anything we have done to date.

I have traveled the world. I have been to most of the climate change conferences. I know the world is now recognizing that without new technologies it cannot get to where it wants to get in relation to certain international protocols.

Do you believe and are you all advocates of moving electrical generation in this country and around the world toward a non-emitting source? And I, of course, must emphasize baseload. And do you support new nuclear-generating technologies to accomplish that? Any of you wish to respond to that?

Dr. MOLINA. Perhaps I can make one comment there, which is along the lines of the report of the National Commission on Energy Policy where these things are documented to much more extent.

What I believe personally is that it is very important for society to leave all options open. And that certainly includes nuclear energy as well. And given the current circumstances, the way society deals with nuclear energy, particularly in this country, including others, unless there is some government intervention to maintain this option, to make it safer, and to have it as a possibility for the future, it will not happen, because there is no incentive for industry to continue doing that.

So I do believe it is very important, particularly along those lines that you mentioned, of having new technologies to move in that direction, to have this option, and for it to be safe. I will not repeat here the problems that we have had, since you are probably very familiar with them, but it does require resources to ensure that this happens. Thank you.

Sir HOUGHTON. May I answer that? I think it is very clear there is no one solution to the problem of getting to a situation within a generation of carbon-free energy. There are many possibilities. And you have mentioned the nuclear one, and that is clearly one of the options that needs considering.

My personal view on that is I am concerned about proliferation of nuclear material. The world really—of course, we are not just looking at the United States, or the United Kingdom, or Europe.

Senator CRAIG. No, we are looking at the world.

Sir HOUGHTON. We are looking at the whole world, which needs these energies. And the proliferation of nuclear material is something we have to be very careful about. And as a long-term solution, I would worry about that. Nevertheless, I do think it has to come into the debate.

The other point I would make is that India and China have a great deal of coal. China is building a gigawatt power station every 5 days at the moment. And so some way, somehow we have to very rapidly move to clean zero carbon coal technology. And that can be done with sequestration.

I know the European Union is going to talk to China later this year about the possibility of helping China with that. I am sure the United States could help China with that also, but it needs to be done rather soon, because they are moving ahead so fast with their greenhouse gas emissions.

Senator CRAIG. Thank you all.

The CHAIRMAN. Okay. We are going to go now, I think it is back to the regular order. Senator Akaka, I think you are next.

Senator AKAKA. Thank you very much, Mr. Chairman.

Dr. Cicerone, in your testimony—and I am following up on Senator Bingaman's question. In your testimony you talked about abrupt climate change; what is abrupt climate change? And can you identify any critical thresholds that might be crossed if we do not take strong action to control carbon dioxide emissions?

For example, I have heard that at certain temperature degree increases, large sheets of ice in the Arctic could melt and collapse, leading to huge increases in sea level. Can you comment on that and other potential threshold events?

Dr. CICERONE. I will try, Senator Akaka. About 2½ years ago or so the Academy did a study and created a report called "Abrupt Climate Change and the Potential for Surprises," largely in response to findings over the last 15 or 20 years that previously the earth's climate was thought to change slowly and gradually. But I would say in the last 20 years or so that scientists, by reading the record of isotopes in minerals and fossils of living organisms, and water pattern flows and so forth, we found evidence of previous climate change on earth. There have been many, many examples of rapid change.

Changes in ocean circulation, for example, that have occurred in periods so short that we are not even sure we are measuring how short they are. Ten to 50 to 100 years instead of thousands of years. So as more of these examples arose in the scientific literature, people began to take more seriously the fact that the earth can change abruptly.

When we try to figure out what those thresholds are, people have had difficulty, and have not yet been able to explain what kind of event could trigger a hemispheric or global change that could occur in 10 to 50 years. I do not think we understand the mechanisms very well yet, but we have powerful evidence that there are mechanisms built into this complicated system that have thresholds connected with them.

So the kinds of examples that Dr. Houghton and Dr. Hurrell gave early are on our minds. We cannot prove it yet. The most recent academy report on abrupt climate change with that title was 2 or 3 years ago. And I can try to extract some more examples to send.

The Antarctic ozone hole that developed over Antarctica, fortunate in some respect that it happened over relatively unpopulated areas, although our colleagues in New Zealand and Australia and southern Chile do not agree with that statement, happened for unknown reasons at the time.

Dr. Molina and his research group, and one of the reasons he was awarded the Nobel Prize in 1995, was helping to come up with the mechanisms that were previously not understood. Thresholds which could cause ozone depletion to occur very rapidly in one place of the world, which were not understood originally.

There must be mechanisms like that in the climate system, too, which are not fully understood yet. We have ideas, plausible ideas, but not proof of where these thresholds lie, in my opinion.

Senator AKAKA. Dr. Cicerone, how would you suggest that island nations and states deal with potential abrupt climate changes? In other words, how likely are they to occur and is there anything we can do now to prevent or prepare for them, as island nations and states?

Dr. CICERONE. I think they generally see the risks much more ominously than we do, with such a large continent and Hawaii and Alaska, as part of the United States. The island nations feel more risk. But generally, the precautions that we can take, by moving our water treatment plants further up the river, further up from sea level, to protect them from saltwater intrusion. Borders that we can put up by moving installations now to prepare for slower changes.

We have so much technology. We have capital. We have scientific ability to foresee that many of the island nations do not have all those ingredients. So they are feeling more threatened. I have not thought from the point of view of island nations, but I know that they take these issues more seriously than we do.

We have been planning over an entire generation of installations to make moves now, which can be done on a cost neutral or beneficial basis, which will not be available if the changes turn out to be sudden, and island nations start to become submerged.

Senator AKAKA. Thank you for your responses, Dr. Cicerone.

Thank you, Mr. Chairman. My time has expired.

The CHAIRMAN. Thank you, Senator.

Let me say to the witnesses, if you wonder what is happening, there is a vote going on, and we are trying to accommodate the voters and you, and not close up shop. So we are going to continue to try to do that.

On our side, Senator Alexander should be next, but he indicated he was going to vote and then come back. Senator Murkowski went. She will be back. Senator Salazar. Then Talent, Thomas. How would we like to proceed? Senator Salazar is not here.

Senator Thomas, did you come here before Senator Talent?

Senator THOMAS. I do not know. Mr. Chairman, I am waiting for some material anyway.

The CHAIRMAN. All right.

Senator THOMAS. So I am happy to yield to my friend.

The CHAIRMAN. We are going to go to Senator Thomas.

Senator THOMAS. All right. Fine. Thank you. We need some scientific effort on how we——

The CHAIRMAN. We need a Nobel Prize.

[Laughter.]

Senator THOMAS. I appreciate you being here. Certainly, all of us understand the importance of this issue. It is a difficult issue. I have been to Milan, to Buenos Aires, to the Kyoto agreements, and our Kyoto conversations, and that lack of agreement, I might say. But it is interesting. And we need to work at it. We are committed to that. I guess the question is: What do we do?

Sir Houghton, you mentioned your studies. Your third IPCC assessment was largely based on the Mann so-called hockey stick graph, which shows neither warming nor ice age. Do you endorse that study, or do you believe that there is still some work to be done?

Sir HOUGHTON. If I could just comment on that. The hockey stick debate is only a very small discussion within the IPCC process. The hockey stick debate addresses the issue of global temperature from the year 1000 to the start of the instrumental record, which began about 1860. Regarding the records since 1860, there is no question of that being correct, because that is a very good record.

Trying to reconstruct the data for the previous period involves proxy data. This is data from tree rings, from pollen sources, from a whole range of indicators of temperature. And those need calibrating against the instrumental record. That calibration process and the way this is done——

Senator THOMAS. I think my point is that there is a difference. As you go to these meetings—and what you have said scientifically is not agreed to by everyone. And so I guess I am saying do we have——

Sir HOUGHTON. Okay. Let me now explain it——

Senator THOMAS. We do not have time to do all the details.

Sir HOUGHTON. No. Well, let me just explain in detail, but let me just say that the point of issue is just the reconstruction of that temperature from 1000 to 1860. Now there are various reconstructions within the literature that is debated within the reconstruction, about those reconstructions. There is nothing within any of those constructions which are being properly published that puts any jeopardy whatever to the main statements of the IPCC regarding the temperature of the 20th century, the increase in that temperature, and all the statements you have heard already.

So there is some debate about it, and I do not dispute that debate. But there is debate about many issues in science, and the whole science of various parts of the IPCC. And that is not a big issue. It is not an issue that affects our main conclusions at all.

Senator THOMAS. Well, it affects the conclusions that we have to make, and you said, as a matter of fact, that we need to be taking some action. Well, the fact is that we are taking action. And the question, if you go to Kyoto, why it is a matter of setting limits, and then some countries trading off and selling their credits to others. It has to do with economy. Nothing to do with the environment.

We are spending more than the rest of the world all put together in doing research—$6 billion a year. I kind of get the impression that we have not made any decisions and we are not moving forward. But what more do you think we can do?

Sir HOUGHTON. What more you could do is to address this issue. And I cannot give you——

Senator THOMAS. Well, we spend $6 billion a year addressing this issue.

Sir HOUGHTON. But that is—it is a big issue. And you have to look at—I am not an economist, and I am not a politician.

Senator THOMAS. No.

Sir HOUGHTON. I am a scientist who comes to this and tells you there is a real problem. The world is facing a real problem. Many countries of the world are taking action to meet that problem. And we just would like the United States to begin to show some leadership in this area so that they are part of the solution as well as not part of the problem.

Senator THOMAS. I am trying to tell you that we are spending more than the rest of the world put together——

Sir HOUGHTON. But then you are emitting more than the world——

Senator THOMAS [continuing]. In seeking to do something——

Sir HOUGHTON. You are emitting a very large—you know, you are emitting——

Senator THOMAS. We have an economy here that is larger than anyone else's.

Sir HOUGHTON. Okay.

Senator THOMAS. I mean it is not easy. It is a different thing to sit there on the scientific end and talk about all these things. It is quite different to say, "All right. What are we going to do about it?" Now I understand that is not your role. It is our role. But we need to talk a little about both sides of the issue. I have used up my time.

Sir HOUGHTON. But Senator, could I just say, we are not just scientists doing it for the sake of the science. Although science is very exciting and very interesting. We believe that there are very severe problems with humankind, severe damages to your country as a result of this.

Senator THOMAS. How about solutions?

Sir HOUGHTON. Severe damages to other countries, too, because——

Senator THOMAS. How about solutions?

Sir HOUGHTON. And the solutions are to move the way we get our energy from being a——

Senator THOMAS. And we are doing more of that anybody else in the world.

Dr. MOLINA. If I can add to that, there are several options. There are many ways to actually address the problem. And the example I gave from the National Commission on Energy Policy is one example I think Senator Bingaman is discussing and considering for action.

It is not enough to do the science. It is not enough to invest, which is terribly important. And the point is, much can be done. It does not have to be Kyoto, but definitely much can be done to start limiting the nations without adverse economic impacts.

You will hear more perhaps from the second panel on the details. We, as scientists, simply expose what the enormous risks might be if we do not do it.

Senator THOMAS. Yes. I understand.

Dr. MOLINA. But we also, as individuals, can, of course, have strong statements that much can be done that is not being done. And that is a point without affecting the economy in a negative way. For example, going beyond voluntary measures to limit the nations. That can certainly be done.

Senator THOMAS. We also have to balance that. I do not want to argue with you, but the economy—we go through this Kyoto, and we go through it all the time. It is not a new issue. And we are trying to find a way to deal with the problem without putting great limits on the economy. And frankly, you can sit in your scientific seat, if you want to, and not worry about the economy, but you cannot do that when you are making the decisions.

Dr. MOLINA. That is why I gave the example of—the specific example of the National——

Senator THOMAS. And you talked about nuclear. France is using nuclear almost entirely. You said maybe we could do it. Illinois, 40 percent of their electricity is already generated by nuclear. It is not a brand new idea. Yes, sir. I am taking too much time.

Dr. CICERONE. I think we all sympathize with the enormous responsibility that you feel. One of the statements that the science academies of the G8 nations and the other three just made was that it is vital that all nations identify cost-effective steps that they can take now to contribute to substantial and long-term reduction in that global greenhouse gas emissions. That statement did not try to make political choices, recognize the need.

I just jotted down seven quick thoughts on the values of energy efficiency that I think we would all agree with. From the United States' point of view, our manufacturing sector uses 50 or 60 percent more energy to produce a widget than, let us say, our competitors in Japan and Germany do. And when the energy costs get as high as they are now, that is a significant fraction of the product cost.

Now if we could help to find ways to manufacture more efficiently, there would be a win-win there. We have a strategic reliance on foreign oil that I do not think any American is comfortable with. If we could increase our energy efficiency and decrease that strategic reliance on foreign oil. You have thought about this a lot.

We have local and regional air pollution issues that, again, arise from the more inefficient burning of fuels for energy. If we could increase the efficiency, we could decrease that problem.

We have a balance of trade issue. I just sketched this out. I could be wrong, but our current usage of foreign oil is contributing maybe $200 billion a year to our trade deficit. We could reduce the trade deficit by increasing our energy efficiency.

We have the climate change issue, where we all want to slow down the emissions of carbon dioxide. If we could increase our energy efficiency with all that means from our business and commercial sector.

We worry about the illicit usages of the money that we are spending on foreign oil. Where is that money going? You probably know the answer better than we do. And I am not sure you have it all either.

And then finally, there is a world market for energy-efficient devices. If we could somehow create incentives for our companies to create those energy—so there are seven win-win-win propositions here.

Senator CRAIG. And those are very good. As you well know, we are right now in the middle of our energy policy development between the House and the Senate, and many of these things are there. And so we are moving in that direction.

Dr. CICERONE. The win-win ones.

Senator CRAIG [presiding]. I hope so. Thank you. I appreciate your specifics.

Senator.

Senator CORZINE. Thank you. And thank the panel. This is an extraordinary presentation that I think should capture the imagination of not just the U.S. public's eye, but globally.

I want to piggyback on Senator Craig. I will probably be—might come at it from a different angle, but I would like each of you to speak to the one or two initiatives that you think, whether it is through conservations or efficiencies, as Dr. Cicerone said, or is it through alternative production elements that you think would fit into the portfolio that we should be investing in to address this issue on a long-term basis. And having been someone who is involved in business, it may not be profitable in the short run, each of those things, but in the long run, may have huge return profiles.

So I would like you, within the best of your judgment, to identify those things that have the highest return profile over some period of time. So it is relatively open ended, but I would like to know what that portfolio of actions are that address what you have so ably described as a real problem for mankind.

Start with Dr. Molina.

Dr. MOLINA. It is a tough question, because my conclusion is that we do need to leave open a whole variety of options. The way I would put it is that what is very important to do is to—there has to be some government intervention that goes beyond voluntary measures to have a strong market signal, so that the market itself chooses what are the best options to limit the emission of greenhouse gases.

Clearly, as Dr. Cicerone pointed out, increasing energy efficiency is a very obvious one. Using the energy sources that do not consume fossil fuels, renewable energy sources——

Senator CORZINE. The fact is, though, that energy efficiencies might not be in the short run 1 year, 2 years, 5 years market viable——

Dr. MOLINA. That is right.

Senator CORZINE [continuing]. Relative to long-term return profiles.

Dr. MOLINA. Yes.

Senator CORZINE. So are the efficiencies that were spoken about, do they have return profiles over a period of time, and where should we be focusing our exploration if we are trying to have the greatest impact on these issues as we go forward?

Dr. MOLINA. Well, just to make the point again, that is why it is very difficult to point any one or two solutions, and you have to let society choose the best. Energy efficiency alone will not solve the problem.

Another very important aspect for the long term, which I consider absolutely essential, is to continue investing in developing new technologies, and in particular, to work with the developing world along these lines.

Senator CORZINE. Such as?

Dr. MOLINA. Well, first of all, there are issues with fossil fuel usage, such as carbon capture. That is in the works. It will, of course, cost more, but society can certainly afford it if it is done properly. So proper use of coal and other fossil fuels without affecting the environment. But then we mentioned——

Senator CORZINE. Mileage standards are efficiency issues that cost more. There is no question. Most of these things cost more.

Dr. MOLINA. If the cost increase is sufficiently slow, society can certainly adapt. I mean in the long run it will be cheaper for society if you consider the costs of not taking these actions.

Senator CORZINE. Okay.

Dr. MOLINA. But I could mention a whole list. There are a series of important papers which have a list of 20, 30 things we could do now and things that you have to do later with new technologies.

Senator CORZINE. Okay. Sir, what are your favorite——

Dr. HURRELL. I am going to give—I am not going to waste your time by trying to guess at that. My hands are full doing the science. My expertise is in the science. I can just make the general statement, as I do in my written testimony, that I feel that there are a large number of technology options, and I think all nations need to work to identify the most cost-effective steps that they can take to help contribute to this problem. I am simply not an expert in this area.

Senator CORZINE. Thank you.

Dr. CICERONE. The reason that I am happy with the answer that we need all of these ideas that you just recommended is we will end up with a more stable solution. During the first oil crisis of 1974 and then in 1979, I was disappointed to find out that there was no magic bullet, no new energy source, or current one that could be exploited that would be cheap, and efficient, and self-reliant.

Now I am much more convinced that what we face is a few percent here and there. By picking up a couple or a few percent here and there, we can make enormous progress. There are markets for all of the new technologies and efficiencies, and we will end up with a more stable, sustainable situation. So you pick up a few percent from the adoption of solar photovoltaic energy for electricity, a few percent from wind, a couple of percent from biomass usage, get started on clean coal technology, and carbon sequestration. But anybody who thinks we are going to find a way to sock away 25 million tons of carbon dioxide per day has not looked at the size of the problem.

Clean coal and carbon sequestration can make a dent, but it is not going to be the total solution.

Senator CORZINE. Nuclear power would fit in——

Dr. CICERONE. Nuclear power. I know of a concept that is being explored now for a nuclear fusion technique which is being supported totally by private investors. Mostly by private investors. A couple of small government grants supporting these people, because the payoff would be so large even though it may not be a total solution.

So a combination of new technologies and improving old ones, inefficiencies, will lead to a dramatic and yet stable solution. But there is not a single magic bullet.

Senator CORZINE. When you say efficiencies, I want to just make sure, is mileage standards one of those that you—on automobiles?

Dr. CICERONE. There is a lot of potential there.

Sir HOUGHTON. I think there is a great deal, except—just to give maybe a view from outside your country, I mean we believe very much in market mechanisms. Capping and trading is a very powerful thing. We have high hopes of Kyoto, as far as that is concerned.

There is efficiency, of course, in buildings, efficiency in transport. Much, much more efficient transportation. Motorcars and the like. And those are all possible, that in a way, they are there. They just have to be built and done.

And the same with buildings. We can cut our—IPCC has said we can cut by 50 percent or so in buildings without too much difficulty. And we should get on with doing that. It needs incentives to do——

Senator CORZINE. I am going to have to get on and vote. I apologize. I would like to——

Sir HOUGHTON. It needs incentives to do that, and we have to—and then we have to work closely and generously with the developing countries, particularly China and India, and other such countries to make sure that we really help them to buildup their economies in ways which are friendly to this whole problem of climate change.

And I know the Chinese are very concerned about it, and the impact on their country of climate change. So are the Indians. They have some very good climate scientists that are well aware of this. They desperately need us to work with them on that. As I say, in Europe, and the European Union is going to work as closely as it can with these countries to try to help them, again, in a generous way, to do things, to buildup their industrial machinery in a way which is, as far as possible, carbon free. Thank you.

Senator ALEXANDER [presiding]. I will ask a question and then Senator Murkowski will.

Let me pursue this line a little bit that was begun by Senator Corzine, but first let me ask, most of our new power plants in the United States are natural gas plants. Natural gas produces methane, is that correct?

Sir HOUGHTON. It is methane.

Senator ALEXANDER. So is making electricity from natural gas contributing to global warming and something we ought to limit or stop?

Dr. CICERONE. Yes. In two ways. But it is also more efficient. The electrical production compared to the amount of carbon used in methane is efficient. We get more efficiency. The typical coal-powered—coal-fired power plant of the past generation had like a 30 percent efficiency. We can do much better than that now, with mixed cycle gas turbines and capturing waste heat, especially with natural gas.

But if the methane, which is the natural gas, is lost before being burned, it is a direct greenhouse emission. And, of course, carbon dioxide is produced in the burning of the natural gas. So it is not a total solution, but the efficiency gain is substantial and can be made even better.

Senator ALEXANDER. Well, let me then go back to the unanimity of your recommendations about why there is—that there is global warming, and that it is caused in significant part by human activity, and that it is urgent we do something about it within a generation. That is a pretty clear message coming from you.

I would argue that the Senate Energy Bill that Senator Domenici, and Senator Bingaman, and the rest of us worked on, without imposing mandates, goes a long way in taking steps to produce low carbon or carbon-free electricity, focusing on, first, conservation and efficiency, second, on advanced nuclear power, third on coal gasification and carbon sequestration, and fourth, on new supplies of natural gas, which you have just said is less harmful, because it is more efficient. And then there is also support for renewable.

But what is surprising and disconcerting to me from the scientific community is how the scientific community with a single voice can say this is a terrifically urgent problem, it is being caused by human activity to a significant extent and we need to deal with it in a generation.

Yet, when we then say, "Okay. So then what do we do about it," you are all over the map and say, "Well, we need a little here, a little there, a little here, a little there." I do not see it, looking at it that way.

I mean the United States of America uses 25 percent of all the energy in the world. Now we are not going to put a few solar panels on or build some windmills and solve the problem in the United States in a generation. And you have mentioned carbon sequestration as the most politically attractive solution. It would be large-scale coal gasification, with carbon sequestration. That solves 15 problems at once. United States, and China, and India. It solves the environmental problems. It is an elegant solution in a scientific term, but it has—but we are several years away from there.

If we were to begin to—we might produce coal gasification very quickly, but carbon sequestration is a massive undertaking. And we do not quite yet know how to do it.

So I am working backward, and if we are talking about the next generation, I do not see any way in the world for a country as large as the United States to reduce the effects of global warming unless we are aggressive on conservation and efficiency, first, and aggressive on nuclear power, second. I do not see any way in the world that scientifically there is a way to limit global warming in the United States unless we do what France is doing.

Now if that is true, why does not the scientific community say that? Because what I always see is let us do a little of this, a little of this, let us build windmills, and put on solar panels. That might be good for a desert island, but it will not solve global warming in the United States of America.

And I believe you would be more persuasive in persuading the Senate and the country that global warming is an urgent issue if you would also say, as Senator McCain did and Senator Lieberman did when they amended their legislation this year and said we want to put mandates on global warming, and we want to incent nuclear power, because in this generation, it already produces 70 percent of all the carbon-free electricity in the United States today. And in this generation, other than conservation and efficiency, it is the only way to do it. Who would comment on that?

Dr. CICERONE. I do not think you would find much disagreement with that, Senator Alexander. I think Dr. Houghton mentioned earlier his personal concerns about spent fuels and potential——

Senator ALEXANDER. Of course.

Dr. CICERONE [continuing]. There are those concerns. There is the——

Senator ALEXANDER. Proliferation and spent fuel are the two worries.

Dr. CICERONE. And we all worry that in the last 20 or 30 years we and other countries have not had an aggressive set of activities to make nuclear power more dependable and more safe. We wish we had. But the numbers are pretty much what you said. The United States gets almost 20 percent of its electricity already from nuclear energy. It has enormous potential. People just want to see it done safely.

Senator ALEXANDER. And yesterday I met for a few minutes with the head of our naval nuclear operation. I mean he runs 103 reactors.

Dr. CICERONE. Tremendous record of safety.

Senator ALEXANDER. I think he has an unblemished record of safety since the 1950's in terms of the reactors. And I jokingly once suggested to him that what we ought to do in the United States is build 20 stripped down aircraft carriers with two 500-watt nuclear reactors and just park them around the coast and plug them into the grid. Because that would be 20 more nuclear reactors than we have built since the 1970's.

At the same time, France is 80 percent nuclear. Japan, who suffered nuclear tragedies, has gone ahead with it. And we are loaning $5 billion through the EXIM Bank to help China build 24. And the President is working with India to help them do that. And I think we should want them to do that, because that will reduce the demand for energy, reducing prices, and it will clean the air, and it will help global warming.

So why does not the scientific community say, "We see the problems with nuclear power," but if you want to deal with global warming in one generation, other than conservation efficiency, nuclear power—it is not a little here and a little there. Nuclear power is the only way——

Dr. CICERONE. The big one.

Senator ALEXANDER [continuing]. To do most of it.

Sir HOUGHTON. Can I just balance that? I mean I do not disagree with the statement you made, but there are two sorts of energy we have not mentioned that much about this morning, which I think in your country can be very important.

One is biomass——

Senator ALEXANDER. But, sir, what percent of our total energy will biomass—today it is about 1 percent of our total energy production. And you are the one who said that in a generation we must deal with this. And what do you think biomass is going to produce?

Sir HOUGHTON. I have seen the program in your country called 25 by 25, which is for 25 percent of your total energy to come from biomass by 2025.

Senator ALEXANDER. Well, sir, if you believe that, then I do not believe what you said earlier about global warming.

Sir HOUGHTON. Well, I do not necessarily—I am just telling you——

Senator ALEXANDER. You undercut your entire credibility when you suggest that 25 percent of our energy will be biomass by 2025.

Sir HOUGHTON. I am posing to you a proposal which has been made, which is probably too ambitious. And I understand that. But I also understand that biomass is important for China, and India, and other countries. And that is the important part of the whole portfolio.

We need a portfolio of possibilities, which includes nuclear, which includes other things, which includes solar as well. Because you have other places where you could——

Senator ALEXANDER. What percent do you think solar will be, sir?

Sir HOUGHTON. Pardon?

Senator ALEXANDER. What percent of the United States do you think solar will be in a generation? You are the one who said it is urgent to deal with this in a generation. And today, solar is less than 1 percent, even though we spent billions of dollars on it.

The CHAIRMAN [presiding]. All right. Senator, this is your last question, please.

Senator ALEXANDER. Well, I have—I am trying to interject some——

The CHAIRMAN. I understand, but, you know——

Senator ALEXANDER [continuing]. Realism——

The CHAIRMAN. You were gracious to take over.

[Laughter.]

Sir HOUGHTON. I am aware of proposals which are being made elsewhere in the world for solar to have a very big part in it. And I also know the potential in your country for, if you really want to do something, doing it fast, doing it well, and doing it efficiently. I am not in the position to say exactly what you can do. But I do urge you to address a portfolio of possibilities, to weigh them all together and what you can do, and come up with a plan for doing it.

And that is what I urge my own government to do in the U.K., what I urge the European Union to do. And I just wish this would be done in a more responsible and a more genuine strategic manner.

The CHAIRMAN. Thank you both.

Senator, thank you. I do not mean to cut you off, but I think even though you are generous to take over when we are not here, you should not assume that the time consumed by you does not count.

[Laughter.]

Senator ALEXANDER. I had an opportunity, Mr. Chairman, and I took it.

[Laughter.]

The CHAIRMAN. You are practical in all respects.

Senator ALEXANDER. Well done.

[Laughter.]

The CHAIRMAN. Now we are going to ask the Senator from Alaska.

Senator MURKOWSKI. Thank you, Mr. Chairman. I kind of enjoyed that little engagement there.

I have said repeatedly, I do not need to be converted on whether or not we have climate change under way in this country. As I said in my very brief statement this morning, I see it in my home State.

I see it with what is happening with the erosion. I see it with what is happening in our vegetation that is migrating northward, with the insects that are coming on, with the temperatures. So I know that something is happening just from a non-scientific person who lives there point of view.

So I have been trying to find what are the answers. Help me with the science. And I have been spending the time that I think a reasonable person in my State would be doing on this issue. I want to know the answers, but I want to know with a certain level of certainty what it is that is causing this. So I listened with great interest this morning to the conclusion that all four of you have reached that it is man's emissions that are causing the changes that I am seeing in my State and the changes that you have referred to throughout the world.

The scientific modeling out there is amazing. And I have had an opportunity to see some of it, talk to the scientists about how it works, and what more we need to do. Why can we not understand and differentiate then what effect the human variables, whether it is the solar changes, or the current changes? What portion can we extract out of this equation and say this is manmade versus this is what Mother Nature is doing?

And if we cannot, why can't we? And will we ever be able to make that distinction, that differentiation? Now I am not going to sit here and tell you from a policy perspective, if you come back and tell me that 5 percent is man-induced and the other ninety-five percent is human variable, that we are going to direct our policy that way.

But are we to the point of understanding from the scientific perspective how we can isolate this?

Dr. Hurrell?

Dr. HURRELL. I will attempt to answer this question probably in two parts. The first speaking to where the technology stands and our ability to differentiate between the human versus more natural origins of the climate change and climate variability.

And, of course, one of the main tools that we have for doing this are the state-of-the-art models of the coupled climate system. And in recent years, I think very credible arguments can be made that these models have become very useful in tackling that specific issue.

If you look at the models now, they are able to replicate, for instance, the most important characteristics of the observed changes in global temperature over the last 100 years. Since they can do that, we can then begin to break down which forces have contributed to the climate change in terms of the increases in temperature that we have observed. If you do those experiments, you find that natural variations and particular changes in solar luminosity played a key role in contributing to the warming during the early part of the 20th century.

But the temperature changes that we have seen in the last several decades, those same simulations with only the so-called natural forces and climate prescribed, do not produce any significant change in temperature over the last several decades.

When you then give the models the information about the observed buildup of greenhouse gases in the atmosphere, they now produce the increase in temperature that has been observed. So this is very strong evidence, I think, from these very credible, although not perfect, but very credible models that much of the climate change over the last several decades is being driven by the buildup of greenhouse gases, and sulfate aerosols and the like in the atmosphere.

Senator MURKOWSKI. Can you define "that much"?

Dr. HURRELL. I would say based on the climate model simulations that are contributing to the next assessment of the IPCC that nearly all of the warming is attributable to that in recent decades.

Senator MURKOWSKI. How do you respond then to those—you have scientists all over the board, like economists, like lawyers, like politicians. You ask them all, they are all going to have their own theory.

I had an opportunity to speak with a climatologist out of Oregon, who is indicating that in his opinion it is the cyclic increase in the solar radiation and/or the changes in the North Atlantic or the Pacific Decadal Oscillations that affect the currents.

Dr. HURRELL. Yes.

Senator MURKOWSKI. So you are saying all of it and he is saying——

Dr. HURRELL. No.

Senator MURKOWSKI [continuing]. Hey, it is all—it is the natural variables.

Dr. HURRELL. Thank you for the opportunity to expand. That gets to the second point of my question. The first point was really addressing the very large-scale temperature changes. On a regional level and a local level you will often hear scientists say that there is more uncertainty in that. And that is because one of the outstanding scientific questions is how will the so-called natural modes of the climate system—you mentioned the Pacific Decadal Oscillation, or El Niño, the ENSO events in the tropical Pacific, which have a worldwide impact on climate and weather.

How will those natural phenomena be affected as a result of human activities? And there is much less certainty on that topic. There are very open scientific issues. So when you look at your State of Alaska, for instance, you have seen warming there that is very significant.

You have noted that you can observe the changes with your own eye. And, in fact, a very key player in Alaskan climate is the so-called Pacific Decadal Oscillation. So there are natural variations in climate that are occurring, that have always occurred in the past. But imposed upon that then is the human influence.

But it becomes much more difficult to attribute at a regional or a local level. For instance, the warming in the Arctic in recent decades. Just how much of that is due specifically in a specific region to the buildup of greenhouse gases. Because a fundamental scientific question is, how do we expect the so-called modes of variability of the climate system to be affected?

Now it is a complicated issue, because in—if I can go on just one more moment. Sir John was speaking about the Atlantic climate. And one of the—the key driver of Atlantic climate, for instance, is something called the North Atlantic Oscillation. It is in some ways analogous to the impact that the PDO has on climate in Alaska.

And scientists have known for a long time that this is a so-called natural mode of climate variability. It is significant year to year, and maybe even decade to decade variations. But there is research that indicates that the amplitude and the phase of this phenomena, which has been behaving differently in recent decades, can be related to the warming of the tropical oceans.

When you look at the warming of the tropical oceans, in particular, for instance, the Indian Ocean, there is very strong scientific evidence to suggest that a big component of that warming of the oceans is, indeed, anthropogenically driven by the buildup of greenhouse gases in the atmosphere.

So you have the warming of the tropical oceans, which are being driven, in part, by the increased greenhouse gas concentrations in the atmosphere that are affecting the behavior of this mode of variability in the system thousands of miles away in the North Atlantic, and are contributing to some of the unusual behavior of this North Atlantic oscillation.

Senator MURKOWSKI. Just so that I am clear that I understand your position, you believe that much, if not all, of what we are seeing that is contributing to climate change, global warming, is caused by man-induced emissions. We may be seeing some regional impact that is perhaps not quite in sync with what we are seeing globally, that is being impacted by the overall global changes.

Dr. HURRELL. Regional climate, if you will, is affected by the weather patterns, the jet streams, and the like. And they are sort of organized in some coherent fashion in the climate system by these large-scale modes of variability. You mentioned the Pacific Decadal Oscillation.

The mechanisms for that can be related to natural couplings in the atmosphere ocean system. Exactly how those couplings are affected by global warming is still a major research issue. So that is what I am trying to separate out, that we know that on a global scale, and we can begin to quantify, I believe, with global climate models, what the human-induced contribution to that overall global warming is. On a local and a regional scale, it is much more difficult to attribute any specific change to the buildup of greenhouse gases in the atmosphere.

Senator MURKOWSKI. I think if you could show this panel here and other policymakers that, in fact, with the statistical modeling, almost entirely we are seeing global climate change as it relates to or caused from manmade emissions, I think it might be easier for us to make a determination in terms of where we go with policy. But when we get statements like we believe that much of it is caused by, that makes it tougher. I think we are looking for a little more certainty.

The one thing that I concluded, sitting down with a group of scientists that were involved with the Arctic climate impact assessment report, was that they all agreed something was happening, but they could not determine exactly where it was coming from. So your assistance on that would help us.

Mr. Chairman, I could go on all morning, but I know we have another panel. Thank you.

The CHAIRMAN. Thank you very much. Did you feel compelled to say something?

Dr. HURRELL. I was simply going to add that I would be more than happy to provide the committee with some of the evidence from the climate model simulations that I am referring to, to show that in a global mean sense, nearly all of the warming in recent decades can be attributed to the buildup of greenhouse gases.

Sir HOUGHTON. May I just add briefly, that is on the global scale we have this confidence that Dr. Hurrell has been talking about, but the regional scale, there is a lot of natural variability. But that natural variability is all being affected by the global scale, by all the global scale changes due to human activity.

But because of the degree of that variability, any given event, we cannot say that event is caused by human-induced climate change, because we have had lots of the variabilities so large. There is one event which I mentioned, which is the heat wave in Europe, which is so far outside. It is five standard deviations away. So far away from natural variability, it could not conceivably have come from natural variability.

But it is most other single events—but it is when we see the way in which the number of events and their average intensity, we can see the trends. And those trends are now occurring. We are seeing more floods, and more droughts, and more storms in general this end of the century that we had in the middle of the century. And the models can actually predict reasonably well or project quite well what will happen by the year 2050, for instance, is what these good models show, that suggest in Europe we are going to have a risk of flooding which is five times greater in 2050 than it is now. So the 50-year flood will become the 10-year flood, and so on.

So we can project into the future, but actually identifying anything now, because of this great natural variability of climate, which is part of the climate characteristic, is made very difficult.

The CHAIRMAN. Thank you very much. Now I guess you noticed that I have not participated, and that is very unusual. But I thought it best to do it the way I did it. I am not sure what is going to happen for the rest of the day to these wonderful following witnesses, but I am going to try to put you on and see what happens. We both have something scheduled, but let us see what happens.

First, let me start, Dr. Cicerone, you indicated that we have evidence over a 400,000-year period that carbon dioxide in the atmosphere had various high and low levels, and you found that out in a typical way that is now determined to be accurate.

Just so we will know, where did the pollutant that contributed then come from? Certainly, it was not what we are doing now. That was not even a civilization. So where did it come from?

Dr. CICERONE. In that range that I spoke of, the last couple of glacial cycles, 400,000 years, the carbon dioxide amounts went between about 180 and 280 parts per million, and today we are about 380.

The CHAIRMAN. Okay.

Dr. CICERONE. So well outside the natural range. But nonetheless, those were big changes, as you say.

The CHAIRMAN. Yes.

Dr. CICERONE. The decomposition of organic material in the soils was going on over geological time scales, and the exchange of carbon dioxide with the oceans. No one can completely tell why the carbon dioxide amounts changed. It looks as if the carbon dioxide changed partly in response to changing climate and partly leading the change in climate over the past two ice ages.

The data are about as firm as we are going to get. They are real measurements from dated ice cores. So it is exchange of carbon with the organic matter in soils and exchange of carbon dioxide with the oceans, the stuff moving back and forth, up and down.

The CHAIRMAN. But the fact that it existed then and we did not have a source of pollutants that we are now trying to control is not a reason to draw any inferences that the information about the current pollutants is not right.

Dr. CICERONE. Correct. First of all, we are way outside the range of natural variability, the 180 to 280. And second, we have isotopic data that tell us that the carbon dioxide buildup in today's atmosphere is mostly due to fossil fuel consumption. Maybe 80 percent.

The CHAIRMAN. My second point. It has been stated by one of you, I think it was you, Sir John, that while China is now and will become, unless some big changes occur, a more major contributor to the CO_2 that we are worried about, and something was said that they are looking for us to do something, it is very interesting, and you should know that we are in the same boat and we have people tell us, we are not going to proceed until they do something.

Now you have answered that by saying you are the leaders. If you lead, they will follow. I want to suggest to you that that is not an easy nut to sell up here. Okay? So I would suggest that we be focusing on how are we doing something that they should recognize that we are doing.

And so I want to tell you something about the energy bill that we produced. We produced an energy bill that essentially, for our new policy, could have been called a clean energy bill, instead of just an energy policy. Because everywhere in the bill the emphasis is on producing energy that is clean. And not only clean, but we have literally used the words, greenhouse gas clean. The whole section on incentives, which is one that Senator Bingaman and I take most pride in, which is going to permit the Secretary of Energy to finance, and we hope we will get it in—the House has not said yes yet. But we are saying we do not get a bill unless it is in there—actually permits the funding in the next few years of facilities that are aimed at reducing greenhouse gases.

And it is going to cost a lot of money, but the way we have done it, it is not going to cost our treasury so much, because it is guaranteed loans where the applicant pays the risk. The risk insurance is paid by them. It may be 10 percent. It may be 5. And that whole section is designed to employ innovative clean energy, and it is actually said that avoid, or reduce, or sequester air pollutants or other emissions of greenhouse gases.

Now if we do that, we pass that law, and we get started on it, is that not evidence that we are doing something? Or is that not the kind of evidence that China or anybody else would be waiting for? Now I just state that—I just throw you that out. I do not need an answer. It seems to me we are going to do something.

Now my last observation, or third observation is this. You heard almost everyone here say with varying degrees that there is a problem. But I think you also gather that the question what do we do about it, and how, remains a very live subject. And while you are not the experts on that, it does appear that you have to be involved in that, and what do we do about it. And I submit that the distinguished Senator from Tennessee, Sir John, was on the right track in talking about practical things. Real things. Not only achievable things. Achievable things that do not amount to anything I do not put in the class of being very relevant.

So when people say we can do this, and we can do that, we have to ask the question, just what will that amount to. And I submit to you that the United States will make a giant stride in nuclear power, and you will see it. I mean it will happen. There will be a nuclear power plant started in the United States within the next 3 years, in my opinion. Sounds crazy, does it not? But I think it will happen. And that is because of this bill and because of what is already happening.

Now having said that, I just make the point that we need to come up with a plan that gives us a period of time to pursue those technologies with vigor, so that we are moving toward achievement and that at some point, if we do not, we do something.

Now the reason Senator Bingaman and I have been drawn to the National Commission on Energy Policy, that they say would end the energy stalemate. It recommends sort of what I am saying, that for X number of years we pursue the voluntary approach, and we want to extend that a little bit to be more consistent with the President's goals, and then we would trigger some things. And then I want to urge that you study that with us, look at it. And I will ask you about it.

The last point is, I do not think the issue is whether we have a major international problem. I think the question is how do we solve it. And I think we have too many people talking as if it is simple. Oh, just cut emissions 10 percent, and come up with a bill that says we should do that.

Well, I hope you understand that I have heard nothing like that from your mouths today. And I thank you very much for your calm expertise here today. And we need more of that, because this country lives on energy. Whether anybody wants to think we are hogs or whatever, we live on energy. And we are successful because of the use of energy. And we cannot put ourselves back in an era when we say we are not using energy without devastating something, right? That is pretty simple.

In fact, I was going to say, Dr. Molina, you do not have to be a Nobel winner to know that, right?

Dr. MOLINA. Right.

The CHAIRMAN. You know a lot more than that. That is very simple. So I am just going to leave it to you for a couple of observations from each of you about what I have said. I am looking for a solution, but I am not going to join the crowd that thinks it is simple. I am not going to join the crowd that thinks Kyoto was a solution. I hate to tell you, it is not a solution. It would not be achieved.

And America, some people think we are being—the President is being stubborn, but I remind you that the U.S. Senate did not have one affirmative vote to support Kyoto when we voted on it. And they keep blaming the President.

Nobody voted to give the President the authority to sign that treaty. So we have to talk about something else. Everybody keeps saying what about it. Well, we have to come up with something else that we can talk about.

Having said that, I am out of time, but usually that means you can use up some time, because mine does not count against you. So would any of you like to comment in any respect.

Dr. Molina?

Dr. MOLINA. Yes. Senator Domenici, as you know I am a member of the National Commission of Energy Policy, so I very much endorse what you just have stated. And I repeat once more, we as scientists, of course, can state what the severity of the problem is, but we do not have the solution. We have to work with the rest of society to do that. And that is why it makes sense to have government intervention, to have a strong signal that something is to be done. It will not happen spontaneously.

We do need enough resources for technology, including clean nuclear energy. So I think you are very much on the right track. We do work with our economist colleagues. And I think there are very sensible solutions. I agree with you, different than Kyoto, but the National Commission on Energy Policy recommendations repeated one very good example that I understand you are looking at very carefully, which is how to go about it without having a negative economic influence on the United States.

Dr. HURRELL. I do not have too much to add. I would reinforce the comments that Dr. Molina made, and I agree with what you are saying, Senator Domenici. I am very heartened to hear from this committee that they feel as though it is not a question of whether or not this is a problem, but rather how to go about addressing it. That is not my area of expertise.

But I have been biting my tongue a bit, because my father-in-law is a nuclear engineer, and I would simply say that I do think that nuclear energy is a very, very real and viable way to make a major contribution to this problem.

Dr. CICERONE. Senator Domenici, as you know, the National Academies of Sciences and Engineering are at your disposal. We exist to help the Government in performing evaluations and recommendations. And in this challenge, we will be at your service.

The CHAIRMAN. Sir John.

Sir HOUGHTON. Just to mention, Kyoto finishes in 2012. Kyoto is not a long-term solution. Kyoto was never meant to be a long-term solution. Kyoto is a beginning. And Kyoto is a beginning that brings nations together to do things. It is also based on market-based techniques and measures. And I notice—and we hope those will work. And they will have some effect.

But we have to look now, we have to begin to look now at the longer term. Beyond Kyoto. Whatever happens there, in order to come up with what you say in your sense of the Senate's resolution, which you passed, you should enact a comprehensive and effective national program of mandated market-based limits and incentives on emissions of greenhouse gases that slow, stop, and reverse the growth of such emissions at a rate and in a manner, and so on.

I mean that is a marvelous statement. That is exactly what we believe should happen. It means that governments, and industries, and local governments, and everybody should get together to work out a program, a timed program of how you can proceed with this. But it is also—it has to encourage comparable action by other nations, for major trading partners, and so on, and key contributors to global issues.

And so there is an international part to it, very important international part to it. And if I might again repeat what I said at the start, coming as I do from outside your country, and listening, as I do, to what the rest of the world says, to a large degree the rest of the world is looking at you in the United States and saying, "Please, United States, you are a big contributor to, of course, the problem of global warming because of your emissions. You have this enormous industrial capacity. You have this enormous desire to lead in the world. And please exercise that leadership, which will enable the rest of the world to come along with you to help to solve this problem."

The CHAIRMAN. Well, for myself, I would just say thank you for the compliment. I wish you would follow in some other areas, too, but it seems to be that we have difficulty getting follow-ship in some other areas of endeavors that are important to us. I am just kidding. Just kidding.

Let us take a look at—do you have anything further, Senator Bingaman, of these witnesses?

Senator BINGAMAN. No, Mr. Chairman.

The CHAIRMAN. Would you join me in thanking them?

Senator BINGAMAN. I think the testimony has been excellent, and I very much appreciate the witnesses and particularly, Sir John, thank you for coming all this distance.

Sir HOUGHTON. Thank you.

The CHAIRMAN. We appreciate it. Thank you all. Thanks for much. You are excused.

Would the other witnesses join with me and let me talk to them a minute? You can sit where you are or come up and let us just chat a bit. Do I understand correctly that each of you, let us say, Dr. Montgomery, do I understand that you are from around here, Doctor?

Dr. MONTGOMERY. Yes.

The CHAIRMAN. The region. How convenient would it be if we set you up again?

Dr. MONTGOMERY. We are all open, sir.

The CHAIRMAN. Would that be all right, Mr. Grumet?

Mr. GRUMET. Around the corner, sir. Can be here any time.

The CHAIRMAN. Okay. Dr. Morgenstern?

Dr. MORGENSTERN. Local.

The CHAIRMAN. Guy Caruso? Local? Okay, with the Energy Information Agency. You have been doing great work, let me say. We greatly and very much appreciate it.

Here is what we are going to do. Rather than try to package this in and shove it into a small time, we are going to reschedule it when we have more time. And you will be first up, the next panel we have. Is that satisfactory? Maybe in the meantime, you have heard a little from us. You might——

Panelist: Improve the quality of our testimony.

The CHAIRMAN. Yes.

[Laughter.]

The CHAIRMAN. Well, answer some—you know what we are thinking about. Yes. Thank you very much. Let me announce that. Thank you.

All right. What we have decided to do, since these four witnesses are from the immediate area, they have expressed a willingness to come back on reasonably short notice, and we will attempt to set up another hearing where they will be first. There will be another panel with them that will address the issues that you have from another vantage point. And with that, I thank everybody, including the members of the press. We stand in adjournment.

[Whereupon, at 12:03 p.m., the hearing was adjourned, to be reconvened on September 20, 2005.]

CLIMATE CHANGE

TUESDAY, SEPTEMBER 20, 2005

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

The committee met, pursuant to notice, at 10:10 a.m. in room SD–366, Dirksen Senate Office Building, Hon. Pete V. Domenici, chairman, presiding.

OPENING STATEMENT OF HON. PETE V. DOMENICI, U.S. SENATOR FROM NEW MEXICO

The CHAIRMAN. Hello, everybody. Good morning, witnesses. Senators, good to be with all of you.

I want to thank all of you for coming here from your busy schedules. As everybody knows, this is a continuation of the hearings that the committee held on July 21. Due to the length of the questions and the answers, and the press of the Senate business, the committee was unable to hear from you. We heard only the first panel. For that, we apologize. Glad we were able to set it up again today.

Today we will hear from four witnesses on the topic of mandatory carbon controls and the impact of such. Now, there could be a lot of other questions asked of you, but I think—and we cannot hold Senators to anything, nor you to your answers, but that is what we would like to focus on, because the previous discussion covered the other subject that was important. So the impact of these controls that we are speaking of, what that might be on the economy and how effective the controls might be in reducing carbon emissions that are generated in the United States.

I should note that the Deputy EIA Administrator, Howard Gruenspecht, is appearing instead of Administrator Caruso and Dr. Anne Smith is appearing in place of David Montgomery. That is just a coincidence of scheduling and we greatly appreciate your stepping in and we know your testimony will be the equivalent of whom you replace.

I am pleased that the committee is continuing the discussion of this serious issue. It is clear that something is happening with the Earth's climate and I am aware that many in the scientific community are warning us that something needs to be done. I am also aware that there are equally-qualified members of the scientific community who do not share those views. Nevertheless, I believe that it is prudent to heed the warnings that we are hearing and begin to find ways of alleviating the human contribution to this problem that is being presented to us.

As I said in the July 21 portion of the hearing, what, who, how and when are the questions that the hearing and subsequent hearings will help us answer. With this hearing we are continuing to search for answers on meaningful economically feasible activities that will produce real reductions in greenhouse gas emissions.

It is clear to me that developing a system of mandatory controls on carbon emissions could be a daunting task. In fact, it is. Controls must be effective. They must produce positive reductions. The cost should have the least possible negative effect and any burdens must be as equal as possible, spread out among those affected.

Now, some say that does not matter, and they have said, when we were arguing on the floor, at least someone did, that we were too concerned about fairness. But, actually, fairness is important in itself, it is also important from the standpoint of Senators and voters and people willing to do things. Many, including the NCEP, suggest that the answer lies in a system assigning greenhouse gas emitters emission allowances that could be sold or traded. The NCEP has also suggested that a monetary value of the allowances be capped at $7 a ton of carbon, rising slowly over 10 years. If needed, emitters could purchase allowances from the government. Proceeds can be used to finance research and development on new or low-carbon energy technologies. I hope I have not misstated the position. I think that is correct.

These are interesting ideas, but designing an effective and equitable allowance mechanism is likely to be very difficult, and I think you yourselves, your group, is acknowledging that. I believe such allocation mechanisms might be constructed, but I do not think we are there yet. I would be glad to hear from you on that score. I guess, not to be trite, but I think the devil is in the details in that regard.

So let us proceed. I yield now to Senator Bingaman. Thank you so much, Senator Bingaman, for helping me move this along and for your interest.

[The prepared statements of Senators Akaka and Corzine follow:]

PREPARED STATEMENT OF HON. DANIEL K. AKAKA, U.S. SENATOR FROM HAWAII

Mr. Chairman, thank you for holding this hearing on the economics of global climate change. First of all, I want to thank ranking member Jeff Bingaman, and you, Mr. Chairman, for your leadership in the Senate's passing the first resolution in support of mandatory control of carbon dioxide during debate on the Senate's energy bill. Included in that resolution was the idea that it should be done in a way that does not hurt the economy. I am very interested in how to do that and I have some questions for the witnesses.

Mr. Chairman, this hearing is extremely timely. In the aftermath of the devastation wrought by Hurricane Katrina, we must consider the economics of *NOT* acting with respect to global climate change.

This is something I have said many times before, but now we have a tragic case. Estimates to rejuvenate the Gulf Coast and to repair New Orleans are in the *hundreds of billions* of dollars, and climbing. The cost to human life and well-being can never be rectified.

It was known that New Orleans was vulnerable, that it is below sea level, and that levees could potentially breach. It is also widely accepted that global warming will bring *stronger* storms, if not more frequent.

The recent article in *Science*, by Dr. Peter Webster, links greater hurricane *intensity* with warmer sea surface temperatures. This is like fueling hurricanes with warmer sea temperatures. This is a devastating thought for all people in low-lying areas such as the Gulf of Mexico. Areas around the Mississippi delta in Louisiana are already sinking, *even as world-wide sea levels are on the rise.* That makes it a triple whammy for Louisiana.

My view, with Hawaii's vulnerability in mind, is that our investment in curtailing the causes of global warming, and our nation's *leadership* in convincing other nations such as China to reduce carbon emission, are critically important for the future. When we discuss economics of carbon control, I have long said that we must weigh the costs of *inaction* as well as the costs of action. Hurricane Katrina is just the first of these wake-up calls.

Thank you, Mr. Chairman, I look forward to the testimony of the witnesses.

PREPARED STATEMENT OF HON. JON S. CORZINE, U.S. SENATOR FROM NEW JERSEY

Mr. Chairman, I would first like to thank you for holding this hearing on the important issue of climate change. Senator Bingaman, thank you, also, for your leadership and advocacy of smart, effective climate change policies.

The consensus among the worldwide scientific community is that the burning of fossil fuels is linked to global warming, and global warming threatens our environment, our health, and our future. It may even be linked to the recent increase in hurricane intensity, and the accompanying dangers.

I strongly supported Senator Bingaman's amendment to the Energy bill proclaiming that the U.S. Senate should take mandatory action on climate change, and confirming the Senate's objective to seriously consider climate change proposals. While this amendment passed the Senate on a bipartisan basis on June 22 of this year, it is a small step on a much larger journey that requires a much greater sense of urgency. Hearings like this one continue to raise awareness of the dangers of global climate change. It is my hope that the words spoken today will translate into comprehensive policies that effectively address global warming, and that we will see action soon.

The overwhelming scientific consensus is that average global temperatures are rising. Though there are natural fluctuations in average global temperatures from year to year and even decade to decade, scientists believe that the rise in temperature we have seen in the later part of the 20th century is due to human factors. Dr. Ralph Cicerone, who was recently hired to head the National Academy of Sciences, asserts that global warming is caused primarily by humans, stating that, "*nearly all climate scientists agree*," with this viewpoint. The NAS was specifically chartered by Congress to advise the government on scientific matters. It would be foolish to ignore their findings.

Many scientists believe we are already witnessing the effects of global climate change in the form of the recent increase in the intensity and frequency of hurricanes. Dr. Kerry Emanuel, an atmospheric expert and MIT professor, believes the higher the temperature of the sea surface, the more intense and greater the duration of hurricanes. In short, scientists believe that global climate change creates meteorological factors conducive to the creation and durability of strong storms. With the aftermath of Hurricane Katrina still fresh in our minds, this consensus should take on an especially strong meaning. If indeed we can create a unified climate change policy that would effectively eliminate or mitigate the effects of rising sea temperatures, we should unhesitatingly do so.

My state of New Jersey, though not as susceptible to hurricanes as the Gulf coast, still sees its fair share of storms during hurricane season. When storms approach New Jersey, we pile sandbags, put plywood up on the windows, and stock up on supplies, much like those in New Orleans did. Such preparations go a long way in attempting to lessen the effects of strong storms. If we can do the same in Congress by passing adequate and meaningful legislation that helps buffer severe weather, don't we owe it to our constituents to do so?

Global warming threatens our environment, our communities and our way of life. It can have a severe economic impact on communities and individuals. We have already seen the devastating economic cost of Katrina. Not only has a billion dollar tourism industry been decimated, but rebuilding an entire metropolis will cost tens of billions of dollars in federal spending. My state, along with all others on the Atlantic coast, is also susceptible to catastrophic damage caused by seasonal storms. If our beaches are threatened, and our coastline damaged, New Jersey will see an economic impact of terrible proportions. Our second largest industry, tourism, simply will disappear without the draw of the Jersey shore. As Katrina has shown all too tragically, every coastal area that we hold dear is at risk of losing a huge part of their states' economies.

I have long been a proponent of legislation that would counter this problem and encourage reductions of greenhouse gas emissions. In the last two Congresses, I secured language in the Senate energy bills creating a greenhouse gas registry. The greenhouse gas registry would have been an important first step in confronting climate changes, and I am committed to continuing to fight for this approach.

And of course, I have been clear about my support for stricter CAFE standards, which I hope, in the wake of Hurricane Katrina, my colleagues will see as just the start of a comprehensive, thoughtful policy to effectively address climate change.

Again, I thank the Chairman and Ranking Member for allowing this Committee the chance to hear from these witnesses before us about this crucial topic. I look forward to their testimonies.

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

Senator BINGAMAN. Well, thank you very much, Mr. Chairman, for reconvening this hearing on climate change and global warming issues. Clearly there are a tremendous number of important issues competing for attention here in the Congress at this time in our Nation's history, and I think it is a tribute to you that you are willing to commit some committee time to continue to look at this issue and see if there is a path forward that we can agree upon.

I would just make three very brief points. First, I am persuaded that there is a broad scientific consensus that links climate change to manmade emissions. There are clearly uncertainties about how the climate is going to change, about what impacts it will have, and various other aspects of the issue. But I believe it makes sense to begin now to hedge against the negative risks involved with climate change and I hope we are able to do that.

Second, I just make the point that in looking at what the effect of any kind of a system of emissions controls might have on the economy, we also need to recognize the effect of inaction on the economy. I do not think that we can ignore the fact that changes are expected, adverse changes in our economy, if we pursue a path of inaction. I think that that is an important issue to have discussed.

The third and final issue is that out of this hearing and others that you may choose to schedule, I hope we can get some consensus on a way forward. Obviously, this is an extremely interesting issue and one that has had an enormous amount of study. Our contribution, if we are able to make a contribution to the debate, is going to be in actually getting agreement on a course of action, and that is what I hope very much this hearing will help us achieve.

Thank you very much.

The CHAIRMAN. Thank you.

Does any Senator feel like they should speak at this point? We are going to have plenty of time. Why do we not do this? Any Senator who would like to can speak for up to 5 minutes.

Senator.

STATEMENT OF HON. CRAIG THOMAS, U.S. SENATOR FROM WYOMING

Senator THOMAS. I am frankly looking forward to your testimony, and thank you for having this. I just note we know that we are facing several items here at the same time. We are looking at energy, how we are going to supply energy. So I hope that you will kind of orient toward policy directions. We can get wrapped up in numbers, but how are we going to balance the things that we need to have energy and to do it in an environmentally sound way?

So we look forward to hearing from you.

The CHAIRMAN. Thank you.

Senator Feinstein.

STATEMENT OF HON. DIANNE FEINSTEIN, U.S. SENATOR FROM CALIFORNIA

Senator FEINSTEIN. I really want to thank you, Mr. Chairman, for having an open mind on this. I think it is really important. I think the situation is changing rather dramatically.

I would like to put in the record a release from the Georgia Institute of Technology and read one quote.* They have just done a study on hurricanes and, quote: "What we found was rather astonishing. In the 1970's there was an average of ten category 4 and 5 hurricanes per year globally. Since 1990 the number of category 4 and 5 hurricanes has almost doubled, averaging 18 per year globally."

So the bottom line is, although there are not more hurricanes, they are much more intense. I spent a day at the Scripps Institute of Oceanography a while back and what they said global warming would do is bring on essentially more erratic weather patterns, that when it rains the drops would get bigger and we would be subject to much more forceful weather conditions. It looks to me as if this is beginning to happen. So I think the ability of this committee, if it is not our SUV loophole closer, if it is not McCain-Lieberman, I think we really do have to come up with some system that will make a difference in reducing global warming gases in the atmosphere.

So thank you very much.

The CHAIRMAN. Anybody else on this side?

STATEMENT OF HON. LISA MURKOWSKI, U.S. SENATOR FROM ALASKA

Senator MURKOWSKI. Mr. Chairman, the only thing I will say, you reminded us at the last hearing. You said it is not really so much the question of whether or not there is a serious problem, but what do we do about it. That is why we are here today, to listen to some of those who do have some specifics. I would agree with Senator Thomas. I would hope we would be able to get into a discussion as to how we actually could make something work. So I appreciate you calling this today.

The CHAIRMAN. Well, I am compelled, Senator Feinstein, to respond to your statement. I was very reluctant, in light of Katrina, to call this meeting because I do not think—I thought somebody would come up with the idea that could be quoted all over the world that Katrina was in some way related to global warming. I have heard one of the best experts in the world on television saying that that is nuts, and I think it is enough for the English to be blaming us and saying we deserve Katrina because we did not sign the Kyoto Agreement, which is also absurd, than to get that spread across here.

So I have great respect for you and I thank you for what you said about my calling the meeting, but I do not think—if we are going

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*The release can be found in the appendix.

to get off on that, we will call a couple of witnesses in the next few days on hurricanes and I think we will find that certainly that is not the consensus opinion.

Senator FEINSTEIN. All I did was quote from a study, Mr. Chairman.

The CHAIRMAN. I understand. Well, I could have had a study, I could have two of them, saying—in fact, I might dig them up and make sure the press gets them.

Having said that, let us proceed. We will take the Federal witness first.

STATEMENT OF HOWARD GRUENSPECHT, PH.D., DEPUTY ADMINISTRATOR, ENERGY INFORMATION ADMINISTRATION, DEPARTMENT OF ENERGY

Dr. GRUENSPECHT. Thank you, Mr. Chairman, Senator Bingaman, and members of the committee. I guess with all the discussion of baseball at last week's hearings I would like to start, as you have indicated, by noting that I am pinch-hitting here for Guy Caruso, who was in the on-deck circle in July when the hearing was postponed, but is traveling out of town today. I know he would have wanted to be here.

I appreciate the opportunity to appear before you today to discuss the Energy Information Administration's recent analysis of policies to reduce greenhouse gas emissions and energy use. EIA is the independent statistical and analytical agency in the Department of Energy. We provide data and analysis to assist policymakers and inform energy markets, but we do not promote, formulate, or take positions on policy issues.

At the request of Senator Bingaman, EIA recently analyzed the impacts on energy markets and the economy that would result from recommendations contained in the December 2004 report issued by the National Commission on Energy Policy; they are represented here and you will hear from them. That analysis and my testimony today focus on a case that includes all of the recommendations made by the Commission that EIA was able to analyze in its modeling system. But we also looked at several of the recommendations separately, including the proposed cap-and-trade program, and I will discuss that as well.

We found that three policies—the cap-and-trade program, which is linked to a target for reducing greenhouse gas emissions intensity beginning in 2010; tighter fuel economy standards for cars and light trucks; and new building and appliance efficiency standards—were projected to have the most significant impact on energy use and emissions of the recommendations made by the Commission.

Overall, the policies we modeled were projected to reduce total energy consumption in 2025 by 5 percent and fossil energy use in 2025 by 7 percent, both relative to the reference case in our Annual Energy Outlook 2005. However, even with those reductions, U.S. consumption of oil, natural gas and coal all grow from today's levels by 2025.

Turning briefly to the individual fuels, the policies in the NCEP package are projected to reduce oil demand by 7 percent in 2025, with a slight decrease in import dependence. As shown in figure 1 of the written testimony, almost all of the reduction in oil demand results from more stringent fuel economy standards. The cap-and-trade program alone has only a small impact.

Second, even though the cap-and-trade program itself would tend to increase the use of natural gas, the NCEP policies taken together are projected to reduce natural gas use slightly by 2025. That is because the NCEP proposals for building standards and some of the technology programs—incentives in the programs—lower natural gas use for space heating and electric generation, and the other programs provide incentives for renewable, nuclear, coal-fired, and integrated gasification-combined cycle generation, which tend to shift generation away from natural gas. Projected coal demand is reduced from its reference case level by about 10 percent in 2025.

Figure 4 in the written testimony shows that the NCEP policies are projected to significantly change the mix of investment in the electric power sector. Again, I mention the integrated gasification-combined cycle capacity additions, which more than double compared to the reference case. Renewable capacity additions increase by nearly 150 percent and total renewable generation is up by 25 percent over the reference case. At the same time, additions of conventional coal-fired generation capacity are less than 25 percent of the reference case level.

The NCEP policies also affect energy prices. Lower demand for energy tends to lower the wellhead or minemouth price of energy, but the cost of emissions permits required under the cap-and-trade proposal adds to the delivered price of energy. So the net impact on the delivered price of energy reflects both of these effects.

So to briefly summarize, the average price of petroleum products to all users is higher by a little bit more, 1.4 percent in 2025, with the NCEP proposals compared to the reference case. In the same year, average natural gas and coal delivered prices are 8 percent and 56 percent higher, respectively. Electricity prices in 2025 are 6 percent higher, reflecting the higher cost of fuels.

By 2025, the NCEP policies reduce energy-related carbon dioxide emissions by 8 percent due to lower energy demand and the change in the fuel mix. Covered greenhouse gas emissions, including gases inside and outside the energy sector, are reduced by 11 percent in 2025.

Figure 5 in the testimony shows the key role of emissions reductions outside the energy sector, which account for more than 50 percent of the total reductions in 2015 and 35 percent of the total reductions in 2025 in the case with all of the NCEP policies, and an even larger share of total reductions from the cap-and-trade policy considered alone. The absolute level of emissions continues to grow in both cases, but at a slower rate than in the reference case.

Economic impacts are clearly another important indicator. By 2025 real gross domestic product in the NCEP case is reduced by .4 percent or $79 billion. That is in real 2000 dollars. As shown in figure 6, the NCEP cap-and-trade program alone is shown to have a smaller impact on the economy.

To conclude, I would like to briefly discuss the relationship of this latest work to earlier analyses that EIA has done. We have looked at the Climate Stewardship Act, the McCain-Lieberman bill, which would have capped greenhouse gas emissions at the 2000 level by 2010 and the 1990 level by 2016. A subsequent version of that, S. 2028, which we also looked at, removed the provision to tighten the cap beginning in 2016.

Like the NCEP proposal, the two versions of McCain-Lieberman have cap-and-trade systems that start in 2010. But the NCEP cap-and-trade proposal is less stringent because it targets a reduction in emissions intensity that allows some growth in the absolute level of emissions and it includes a safety valve on the price of emission permits. Either version of the Climate Stewardship Act is projected to result in larger energy system changes and larger reductions in energy-related emissions than the NCEP package as a whole or its cap-and-trade proposal alone. Figure 8 in my written testimony shows emissions permit prices are significantly higher for those proposals.

Another observation is that the safety valve feature of the NCEP cap-and-trade proposal protects against the possibility of large changes in the energy system and energy prices and of large economic impacts if reducing emissions is more costly than expected. However, if the safety valve becomes effective, emissions will be permitted to rise above the targeted level. So you have insurance on the cost, but on emissions levels you have more uncertainty.

So policies with a firm cap on emissions provide emissions certainty regardless of cost to the energy system and the economy, and, therefore, when you are looking at that type of proposal, estimates of energy system and economic costs are subject to much greater uncertainty.

That concludes my testimony. Thank you and I will be happy to answer any questions you might have.

[The prepared statement of Dr. Gruenspecht follows:]

PREPARED STATEMENT OF HOWARD GRUENSPECHT, DEPUTY ADMINISTRATOR, ENERGY INFORMATION ADMINISTRATION, DEPARTMENT OF ENERGY

Mr. Chairman and members of the committee, I appreciate the opportunity to appear before you today to discuss the Energy Information Administration's (EIA) recent analyses of greenhouse gas reduction policies.

EIA is the independent statistical and analytical agency within the Department of Energy. We are charged with providing objective, timely, and relevant data, analyses, and projections for the use of Congress, the Administration, and the public. We do not take positions on policy issues, but we do produce data, analyses, and forecasts that are meant to assist policy makers in their energy policy deliberations. Because we have an element of statutory independence with respect to this work, our views are strictly those of EIA and should not be construed as representing those of the Department of Energy, the Administration, or any other organization.

My testimony today will focus on EIA's recent assessment of the impacts on energy supply, demand, and the economy that would result from the recommendations proposed in a December 2004 report entitled *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges*, prepared by the National Commission on Energy Policy (NCEP), a nongovernmental privately-funded entity. ETA's report, *Impacts of Modeled Recommendations of the National Commission on Energy Policy*, released in April 2005, compares cases incorporating the NCEP recommendations to the projections of domestic energy consumption, supply, prices, and energy-related carbon dioxide emissions through 2025 in the reference case of the *Annual Energy Outlook 2005* (*AEO2005*). *AEO2005* is based on Federal and State laws and regulations in effect on October 31, 2004. The potential impacts of pending or proposed legislation, regulations, and standards—or of sections of legislation that have been enacted but that require funds or implementing regulations that have not been provided or specified—are not reflected in the projections. *AEO2005* explicitly includes the impact of the American Jobs Creation Act of 2004, the Military Construction Appropriations Act for Fiscal Year 2005, and the Working Families Tax Relief Act of 2004. *AEO2005* does not include the potential impact of energy legislation that is now being considered by the Congress or regulations such as the Environmental Protection Agency's (EPA) Clean Air Interstate and Clean Air Mercury rules that were promulgated earlier this year.

The projections in the *AEO2005* and our analysis of the impacts of the NCEP policy recommendations are not meant to be exact predictions of the future but represent likely energy futures, given technological and demographic trends, current laws and regulations, and consumer behavior as derived from known data. EIA recognizes that projections of energy markets are highly uncertain and subject to many random events that cannot be foreseen such as weather, political disruptions, and technological breakthroughs. In addition to these phenomena, long-term trends in technology development, demographics, economic growth, and energy resources may move along a different path than expected in the projections. Both the *AEO2005* and our report on the NCEP policy recommendations include a number of alternative cases intended to examine these uncertainties.

Since ETA's report has been provided to the committee and is available to the public on EIA's web site, my testimony presents only a summary of its key findings. My testimony focuses on the NCEP case in our report, which includes all of the NCEP recommendations that EIA was able to model. However, I will also discuss some results for individual recommendations modeled separately, such as the proposed cap-and-trade program (CAP-TRADE case) linked to an intensity target for greenhouse gas (GHG) emissions, the proposed fuel economy standards (CAFE case), and the deployment incentives (INCENT case). Then, I will turn to sensitivity cases that highlight the effect of alternative technology assumptions on our results. Lastly, I will offer some comparisons to findings from some previous EIA analyses of policies to limit GHG emissions.

MAIN RESULTS OF THE EIA ANALYSIS

The December 2004 NCEP report outlined a broad array of policy measures, not all of which were amenable to analysis using the EIA model of U.S. energy markets, the National Energy Modeling System (NEMS). Our analysis focused on the recommendations that could be modeled and which were thought to have a significant potential to affect energy consumption supply and prices. Where the NCEP recommendations required further specification, specific assumptions were developed in consultation with staff of the requesting committee.

Our results show that the largest projected impacts on emissions, energy production, consumption, prices, and imports result from three of the NCEP recommendations: the cap-and-trade program linked to an intensity target for GHG emissions beginning in 2010, a major increase in corporate average fuel economy (CAFE) standards for cars and light trucks, and the new building and appliance efficiency standards. Other recommended policies generally affect specific fuels or technologies but do not have large overall market or emissions impacts.

The impacts of the modeled NCEP recommendations, analyzed together unless otherwise noted, relative to the *AEO2005* reference case, are discussed below.

Energy Consumption

Primary energy consumption is 2.26 quadrillion Btu (1.9 percent) lower in 2015 and 6.73 quadrillion Btu (5 percent) lower in 2025 as the combination of efficiency programs and new CAFE standards reduces energy demand. Fossil fuel energy consumption is 2.5 quadrillion Btu (2.4 percent) lower in 2015 and 8.1 quadrillion Btu (6.9 percent) lower in 2025. In absolute terms, the use of all fossil fuels is projected to grow from 2003 levels through 2025.

*Figure 1** illustrates the impacts of the NCEP policies on oil consumption. Oil consumption in the NCEP case is 0.83 million barrels per day (3.4 percent) lower in 2015 and 2.1 million barrels per day (7.4 percent) lower in 2025. The import share of petroleum product supplied declines from 62.4 percent to 61.3 percent in 2015 and from 68.4 percent to 66.8 percent in 2025. As shown in *Figure 1* almost all of the projected reduction in oil consumption results from the recommendation to increase fuel economy standards (CAFE case). More than two-thirds of oil consumption is currently used in the transportation sector, and the transportation share of total oil use is projected to grow to 71 percent in 2025 in the reference case. Because of the GHG permit safety valve, which caps the price of traded permits at $6.10 per metric ton of carbon dioxide (CO_2) in 2010 rising to $8.50 per metric ton in 2025 (2003 dollars), the maximum direct effect of the cap-and-trade policy on the delivered price of gasoline, diesel, or jet fuel is roughly 7 cents per gallon (2003 dollars).

* Figures 1-9 have been retained in committee files.

Taken alone, a 7-cent price increase is not expected to spur either a switch to alternative fuels or prompt a significant increase in fuel efficiency (CAP-TRADE case).

Figure 2 illustrates the impacts of the NCEP policies on natural gas consumption. Natural gas consumption in the NCEP case is slightly lower (0.45 quadrillion Btu or 1. 6 percent) in 2015 and 1.1 quadrillion Btu (3.6 percent) lower in 2025, due mainly to lower electricity demand from the building standards recommendation and the incentives provided for deployment of renewable, coal-fired integrated gasification combined-cycle (IGCC), and nuclear power plants that further reduce the size of the market for natural-gas-fired electricity generation. In contrast, when the cap-and-trade program is considered alone (CAP-TRADE case), projected natural gas consumption rises above the reference case level as natural gas replaces coal in electricity generation.

Figure 3 illustrates the impacts of the NCEP policies on coal consumption. Coal consumption in the NCEP case is slightly reduced (0.46 quadrillion Btu or 1.8 percent) in 2015 and more significantly reduced (3.0 quadrillion Btu or 9.8 percent) in 2025, due mainly to the lower electricity demand and shifts in the generation fuel mix that are caused by the cap-and-trade program. The technology incentives and building standards packages have offsetting effects on coal use, by encouraging IGCC plants while reducing electricity generation, so the net effect on coal use of the cap-and-trade program alone (CAP-TRADE case) is similar to that of the combined NCEP policy case.

Figure 4 shows how the NCEP policies affect projected electric generation capacity additions over the 2004 to 2025 period. Because of the early deployment incentives (INCENT case) and the cap-and-trade proposal, projected IGCC capacity additions more than double, and renewable generation increases by 23 percent relative to the reference case. However, the projected capacity additions of conventional coal-fired technology decline to less than 25 percent of the reference case level. The shift from conventional coal-fired plants to more efficient IGCC plants results in an increase in the amount of generation per ton of coal consumed.

Energy Prices

The NCEP policy recommendations generally reduce the demand for fossil fuels, which tends to lower wellhead or minemouth prices. However, the cost of permits required under the cap-and-trade program tends to increase the delivered price of fossil fuels. When these effects are taken together, the cost of permits tends to dominate even with the safety-valve limit on permit prices in place, so the energy prices paid by end users generally rise.

The average petroleum price to all users (including the price of emissions permits) is 2.2 percent higher in 2015 and 1.4 percent higher in 2025 than in the reference case, with the permit prices more than offsetting the lower crude oil prices resulting from the new CAFE standard. When the cap-and-trade (CAP-TRADE) program is considered without new fuel economy standards, the reduction in oil demand is much smaller, so the expected impact on delivered petroleum prices is larger.

The average delivered natural gas price in our NCEP case is $0.17 per thousand cubic feet (2.7 percent) lower in 2015, with the wellhead cost reduction partially offset by the increased GHG permit price, and $0.52 per thousand cubic feet (7.6 percent) higher in 2025, largely because of the permit price which is added to the delivered fuel costs. The 2015 result reflects the impacts of building and appliance standards, which reduce residential electricity demand, and incentives for IGCC, which favor coal-fired generation relative to natural gas.

When the costs of emissions permits are included, the average delivered coal price is $0.54 per million Btu (43 percent) higher in 2015 and $0.74 per million Btu (56 percent) higher in 2025 than in the reference case because of the high carbon content of coal. The much higher percentage change in delivered coal prices compared to the other fossil fuels reflects both its high carbon content per unit of energy and its relatively low price in the reference case.

The average delivered electricity price is projected to be unchanged in 2015 but is 0.4 cents per kilowatt-hour (5.8 percent) higher in 2025 because of the mandatory cap-and-trade program. EIA's electricity price estimates reflect the assumption that consumers capture the economic benefits of the allocation of GHG permits to regulated utilities in areas of the country where electricity rates are set under cost-of-service regulation.

Emissions

Projected reductions in energy-related CO_2 emissions, which are concentrated in the electric power and transportation sectors, are 2.8 percent in 2015 and 7.7 percent in 2025. These reductions are larger than the corresponding reductions in primary energy use (1.9 and 5.1 percent, respectively for 2015 and 2025), as the NCEP policy recommendations promote a less CO_2-intensive energy mix.

Covered GHG emissions are 393 million metric tons equivalent (5.2 percent) lower in 2015 and 964 million metric tons CO_2 equivalent (11 percent) lower in 2025. Covered GHG emissions intensity decreases by 5.1 percent in 2015 and by 10.6 percent in 2025. The absolute level of covered GHG emissions is projected to grow at an annual average rate of 1.1 percent over the 2003 to 2025 period, compared to annual average growth of 1.5 percent in the reference case.

As shown in *Figure 5*, reductions in emissions of non-CO_2 GHG emissions, which are not represented in a detailed fashion in NEMS, account for over 50 percent of the covered GHG emissions reductions in 2015 and 35 percent of the covered GHG emissions reductions in 2025. Estimates for non-CO_2 GHG emissions were developed using emissions baselines and abatement cost curves based on engineering cost estimates that were supplied by EPA. Real-world factors affecting the behavior of decisionmakers and the use of incomplete cost information may result in an overstatement of the actual level of non-CO_2 abatement achieved at each level of the permit price. However, as discussed below, due to the safety-valve feature of the proposed cap-and-trade program, the projected energy sector and economic impacts of the NCEP policy recommendations would not change significantly even if the assumptions used regarding the supply of GHG abatement opportunities were too optimistic.

Because of the safety-valve price mechanism in the cap-and-trade program for GHGs, the GHG intensity targets specified by the NCEP are not reached. EIA projects that total emission reductions fall short of the emission target by 557 million metric tons CO_2 equivalent in 2025.

Economic Impacts

Figure 6 shows the projected effect of t1 NCEP policy recommendations and the cap-and-trade policy considered separately on the projected level of real gross domestic product (GDP). By 2025, real GDP in the NCEP and CAP-TRADE cases are, respectively, 0.4 percent ($79 billion dollars) and 0.13 percent ($27 billion dollars) below the reference case levels. These changes do not materially affect average economic growth rates for the 2003 to 2025 period. Real consumption is also reduced over the 2010 to 2025 period relative to the reference case, with the impact reaching about 0.55 percent in 2025 ($74 billion in year 2000 dollars).

Cap and trade systems or emissions taxes are generally considered the most economically efficient approach for reducing emissions, since they allow reductions to be made where they can be achieved at the lowest cost. In a pure cap-and-trade program, the price of emissions permits, which generally rises as the cap is made more stringent, is a good indicator of economic impacts. However, in a program that combines a cap-and-trade program with regulatory measures, a lower permit price does not imply lower economic impacts. Although the regulatory measures included in the NCEP case result in a lower projected price of emissions permits than would be expected if the cap-and-trade policy was implemented alone, the projected economic impacts in the NCEP case are higher than for the cap-and-trade only case in our analysis.

TECHNOLOGY SENSITIVITIES

While the *AEO2005* reference case used as the basis for comparisons in our analysis incorporates significant improvements in technology cost and performance over time, it may either overstate or understate the actual future pace of improvement, since the rate at which the characteristics of energy-using and producing technologies will change is highly uncertain. Relative to the reference case, ETA's high technology case generally assumes earlier availability, lower costs, and higher efficiencies for end-use technologies and new fossil-fired, nuclear, and nonhydropower renewable generating technologies.

Although the NCEP recommends increases in the funding for research and development, EIA, consistent with its established practice in other recent studies, did not attempt to estimate how increased government spending might specifically impact technology development. Instead, to illustrate the importance of technology characteristics in assessing the impacts of the NCEP recommendations, EIA prepared a set of NCEP policy cases using its high technology assumptions. *Figure 7* shows how the use of high technology assumptions tends to reduce projected energy use with or without the recommended NCEP policies. Relative to the *AEO2005* high technology case, the high technology case combined with the NCEP recommendations reduces fossil fuel use by 1.46 quadrillion Btu (1.5 percent) in 2015 and 4.48 quadrillion Btu (4.1 percent) in 2025.

Under the high technology assumptions, the NCEP's greenhouse gas intensity goals are met, reducing covered GHG emissions intensity from 480 to 463 metric tons CO_2 equivalent per million dollars of GDP in 2015 (3.5 percent) and from 405 to 373 metric tons CO_2 equivalent per million dollars in 2025 (7.9 percent). Attainment of the emissions intensity goal depends heavily on estimated reductions of non-CO_2 GHG emissions, subject to the caveats above and on the use of banked GHG emissions permits that are exhausted in 2025, at the end of the forecast horizon for this analysis. Because energy consumption is already lower in the high technology case than in the reference case, the NCEP recommendations have a smaller relative impact to the high technology case. However, due the lower baseline consumption, the GHG intensity goals are easier to attain.

RELATIONSHIP TO PREVIOUS EIA GREENHOUSE GAS ANALYSES

EIA has completed several other reports on policy proposals to limit or reduce GHG emissions. EIA's previous analyses of emission reduction proposals indicate that the economic impacts are largely determined by the *size of the energy market change* required to satisfy the policy *and the speed* with which the change must occur. In 2003, EIA considered the original version of the Climate Stewardship Act (S. 139), which would cap GHG emissions at the 2000 level in 2010 and the 1990 level in 2016 and beyond. In 2004, EIA considered an amended version of that bill (S.A. 2028) that removed a provision for a tightening of the emissions cap beginning in 2016. The NCEP proposal, S.A. 2028, and S. 139 all have a 2010 start date for their cap-and-trade systems. The NCEP proposal is less stringent than the others because it is expressed in terms of GHG emission intensity, starts from the 2010 level, and includes a safety valve.

These earlier reports suggest that either version of the Climate Stewardship Act is projected to provide larger reductions in emissions from the energy sector than the NCEP policy recommendations. To achieve this, higher permit prices (*Figure 8*) and larger energy system changes, particularly for electricity generation and demand, are required.

That is, S.A. 2028 and S. 139 would require more significant changes in the U.S. energy system and larger increases in delivered energy prices than the NCEP recommendations, resulting in larger estimated economic impacts. As permit prices increase, electricity prices typically increase and reduce demand while electricity generation tends to shift away from coal technologies because of the high carbon content of the fuel and toward low or no-carbon emitting technologies like renewable, natural gas, and nuclear power generation (*Figure 9*).

Finally, while all baseline and policy projections are inherently uncertain, differences in policy design can affect the impacts on the energy system and the level of GHG emissions. The safety-valve feature of the NCEP cap-and-trade proposal would allow GHG emissions to rise above the level projected in our report in the event that emissions reduction inside or outside the energy sector proves to be more costly than we expect, while protecting against the prospect of larger energy system and economic impacts in these circumstances. In contrast, policies that impose a "hard" cap on emissions without a safety-valve price for GHG credits, would force the GHG emissions target to be met through higher GHG prices, regardless of the cost to the economy.

This concludes my testimony, Mr. Chairman and members of the Committee. I would be pleased to answer any questions you may have.

The CHAIRMAN. Well, I want to thank you very much for your concise and understandable testimony. We appreciate it.

Dr. Smith.

STATEMENT OF ANNE E. SMITH, PH.D., VICE PRESIDENT, CRA INTERNATIONAL

Dr. SMITH. Mr. Chairman, members of the committee, thank you for your invitation to participate in today's hearing. My name is Anne Smith. I am an economist and a vice president at CRA International. The opinions I will be presenting here are my own and not those of my company, CRA International.

The role of technology frames the entire climate policy decision. If we believe the conclusion of climate scientists, then we must act to stabilize greenhouse gas concentrations at some level in order to achieve significant reductions in climate risk. To accomplish this goal by about mid-century, this century, all new global energy needs will have to be satisfied from essentially carbon-free sources. That takes more than a few percent reductions here and there.

No technologies available today, even as a group, are capable of providing this much carbon-free energy at an acceptable cost, and that fact makes the central challenge of climate policy all about stimulating breakthroughs that will lead to entirely new technologies that can accomplish this goal.

None of the emissions limitations or the safety valves or subsidies proposed in the NCEP or by Senators McCain or Lieberman or in the amendment proposed by Senator Bingaman provide adequate incentives for this research and development, or R&D. Caps on emissions starting in 2010 can only motivate use of currently available technology and, although an assurance of high future carbon prices could motivate investment in the R&D that is required to create these radically new technologies, unfortunately the safety valve limits the rate of increase in carbon prices to a level that is too slow—too low, sorry, to stimulate that R&D.

Now, even choosing a higher rate of escalation in the safety valve price would not work because it would not provide a credible private sector incentive for the R&D. The reason for this is explained more in my testimony, my written statement, but this is because once new technologies are developed then the most attractive choice for a future government will be to allow those allowance prices to fall down to the lowest level possible to incentivize the uptake of those new technologies. But that carbon price will never be high enough, that low carbon price will never be high enough to provide an adequate reward to the firms, the private sector firms, who invested in the R&D. This is because there is a fixed cost to R&D and by the time the technologies are available that fixed cost and expenditure by the private sector will be sunk and it will not be necessary for the government to ex post pay them back in order to get the technologies adopted.

So here is the Catch-22 we face. Any announced future carbon price that is high enough to induce the breakthrough R&D would not be credible and any carbon price that is low enough to be credible as a sustainable policy in the United States would not be sufficient to induce the R&D breakthrough.

Some people are saying that subsidies are necessary in combination with the safety valve price to achieve the needed R&D. In fact, the kinds of subsidies that are proposed in the Bingaman amendment and the NCEP proposal would only promote technologies that can be built at near-commercial scale today or in the very near future.

If anything, this would just help—these subsidies would just help lock into place the current ways of reducing emissions, that would become obsolete if the R&D that we need becomes successful.

The approach of layering subsidies onto a safety valve actually reveals that the policy, the safety valve policy that has been proposed with subsidies, would not be as cheap as the safety valve price would suggest. Consider this. If the safety valve price is set at a level that is supposed to be the maximum acceptable cost that our country is willing to spend on near-term emissions reductions now, then the subsidies represent an end run around that spending limit. They directly cause spending on projects that cost more and exceed the price of the safety valve on a dollars per ton reduction basis.

This is how it happens. The private sector will be willing to pay up to an amount equal to the safety valve price and then the Government will use funds that it has collected from the private sector to pay even more for those same projects. So the policy will be more expensive than advertised.

Now, that might be justifiable if the policy were to provide incentives for breakthroughs toward a zero emissions world, but for reasons I have already explained it will not do that.

So I want to be clear. Placing an economy-wide price on carbon emissions before the R&D is accomplished can be justified as a supplement to a meaningful R&D mission, but we need to first figure out what the R&D goals and targets are before we know how to set that price for today.

I also want to be clear, the safety valve is a far better way to achieve this role of achieving near-term emissions reductions that are affordable than a hard cap. A low price on carbon emissions can serve to motivate low-cost emissions reductions and including a safety valve is important to limit the damage to the economy that could occur under a hard cap.

But if setting a stable price, a stable and low price on carbon emissions, is the only near-term objective of the policy, then the rest of the cap-and-trade system is not needed and a carbon tax would do just as well.

Some people think that a cap-and-trade system is better than a carbon tax approach and in part this is because the carbon cap approach allows the Government to make valuable allowance allocations to help offset the burden. But they are mistakenly believing that a carefully devised allocation scheme could make everybody better off and this is simply not possible. This I have also explained in detail in my written statement, the reasons for that.

The possibilities of allocations, allowance allocations, does not make a cap-and-trade system any more cost-effective than a tax and yet, as we have seen, it can greatly complicate the process of getting the policy into place.

Now, the safety valve is neither more nor less than a carbon tax and it would simple, more simple, more transparent, to propose a carbon tax than to devise a costly and complex apparatus of emissions trading to achieve what is a fairly modest goal of setting a low and stable price on carbon emissions.

Now, I believe that the focus of the current debate on how to set a safety valve or a cap is encouraging policymakers to neglect the much more important and more urgently needed actions for reducing climate risks. The top priority for developing a climate change policy should be a greatly expanded government-funded R&D program, R&D, not subsidy program, along with concerted efforts to reduce barriers that currently limit technology transfer to developing countries, where some cheaper near-term reductions could be achieved now.

Both of these actions present major challenges and both must really be initiated immediately if they are going to have their desired effect in time to achieve the long-term emissions reductions that we want. Yet they are receiving minimal attention from policymakers, who are transfixed by the challenges of creating an unnecessarily complex scheme to set a low price on current carbon emissions even though that component of the climate policy will provide no reduction in climate risk.

So thank you for the opportunity, giving me an opportunity to share my views on this important topic. I would be happy to answer questions.

[The prepared statement of Dr. Smith follows:]

PREPARED STATEMENT OF ANNE E. SMITH, PH.D., VICE PRESIDENT, CRA INTERNATIONAL

Mr. Chairman and Members of the Committee, thank you for your invitation to participate in today's hearing. I am Anne Smith, and I am a Vice President of CRA International. Starting with my Ph.D. thesis in economics at Stanford University, I have spent the past twenty-five years assessing the most cost-effective ways to design policies for managing environmental risks. For the past fifteen years I have focused my attention on the design of policies to address climate change risks, with a particular interest in the implications of different ways of implementing greenhouse (GHG) gas emissions trading programs. I thank you for the opportunity to share my findings and climate policy design insights with you. My written and oral testimony today is a statement of my own research and opinions, and does not represent a position of my company, CRA International.

I would like to start by summarizing what I think are the most important and overarching considerations that should be accounted for in devising a sound and effective policy to mitigate risks of climate change. I will then provide a basis for these points, present more extensive detail on the trade-offs in policy design alternatives, and summarize results of analysis my colleagues and I have done of the comparative costs and effectiveness of proposals now before the Congress.

The key points that I have to offer about designing an effective climate change policy are:

- The linkage between *near-term* domestic GHG reductions and real reduction of climate change risk is, for all practical purposes, nonexistent. Near-term domestic controls cannot have any meaningful impact on global emission levels at any cost that is currently deemed realistic. Such policies also will not stimulate the kinds of technological progress necessary to enable meaningful emissions reductions later on (because one can expect that carbon prices will be driven to the lowest level necessary to incentivize *adoption* of important new technology—a level that is too low to provide innovators with a return of their one-time investment cost).
- The current debate about how to impose ineffectual near-term controls is encouraging policy makers to neglect much more important, more urgently needed actions for reducing climate change risks. The top priority for climate change policy should be a greatly expanded government-funded research and development (R&D) program, along with concerted efforts to reduce barriers to technology transfer to key developing countries. Neither of these will be easy to accomplish effectively, yet they are receiving minimal attention by policy makers.
- Developing *new* technologies is crucial and it will require long-run, high-risk, high-cost R&D to produce radically new GHG-free energy sources. Even with moderately expensive GHG limits, the private sector will under-invest in this kind of R&D, and only government can provide the needed R&D investment. The existing climate policy proposals, including the McCain/Lieberman (M/L) Bill and the NCEP or Bingaman proposals, focus on providing subsidies to existing technologies rather than R&D aimed at developing new technologies. New government efforts to pick winning technologies and subsidize their deployment would probably undermine the cost-effectiveness of any emissions control program, without producing the forward-looking R&D that we really need.
- Although no near-term emissions control program will have much impact on solving the climate problem, a price on carbon in the near-term can be justified as a supplement to a meaningful R&D mission once that mission has clearly defined targets for success. The near-term control program's role would be to stimulate emissions reductions that can be achieved now more cheaply than the present value of future control costs targeted by the R&D program; the max-

imum near-term carbon price could therefore be determined by discounting the R&D program's defined targets for technology costs and dates of commercial availability.

- The design of such a policy for near-term emissions control matters tremendously. CRA's modeling work and the economics literature indicate the relative cost-effectiveness of the various options for the climate change situation.

a. Hard caps are the most costly and least desirable option.

b. The safety valve approach and carbon taxes are alternatives to hard caps that are much less costly, and that are more consistent with the inherently subsidiary role of any near-term reductions program. (The contrast between a safety valve and hard cap approach is especially evident in my comparison below of results of CRA's modeling of the McCain/Lieberman Bill and the cap program of the Bingaman Amendment.)

c. One factor highlighted by CRA's work but often slighted in other analyses is the possibility of using allowances to limit the costs of controls. Domestic GHG controls will cause small but not trivial losses of government revenue. Auctioning some of the allowances and using proceeds to offset other expected reductions in Federal revenue would noticeably reduce the program's total cost to society.

d. There are no simple analytical methods for determining allocations of allowances to individual companies or sectors to equitably mitigate the financial impacts of the policy.

e. There is no allocation design that can make all affected parties better off under a cap-and-trade or other carbon pricing policy.

f. The inherent complexity of a safety valve approach does not appear to be justified compared to a simpler carbon tax. A carbon tax would provide identical emissions reduction incentives at identical costs to those of the safety valve proposal without the political, institutional, and analytical complications apparent in today's safety valve proposals.

To provide a foundation supporting the above statements, I will begin with a review of the basic elements of climate science and projections of future greenhouse gas emissions that are relevant to economic questions about the design of climate policies. In section 2, I will describe the range of potential policy designs, which include carbon-pricing schemes and technology strategies. Section 3 will focus on just the carbon-pricing approaches in more detail, and will include a comparative analysis that my colleagues and I have done of the costs and effectiveness of proposals now before the Congress. I will address costs and risks to the economy from different policy designs, the ability of economically feasible mandatory caps on emissions to accomplish long-term climate goals, the role of allocations in policy design, and alternatives to "mandatory limits on greenhouse gas emissions." In Section 4, I will turn to technology strategies. I will explain the reasons for my conclusion that the most important first step for the Congress to take in developing a cost-effective US climate policy is to provide incentives for R&D into new energy technologies.

In all of the following, I wish to be clear that I use the term R&D as a distinctly different concept from providing subsidies for the initial uptake of existing but yet-to-be deployed technologies. By R&D, I mean investment to create technologies that do not exist today, and which would require major new scientific breakthroughs before they could become an option that any private entity might consider proposing in a competition for actual implementation under a subsidy program. The R&D may entail basic science as well as work that is identifiably on an energy technology with low or zero carbon emissions. Subsidies are aimed at bringing technologies into the market, and by definition, such technologies must be already reasonably well developed, if not yet cost-effective to use under current prices without supporting funding. There may be a sometimes unclear line dividing the two, but it is clear that we do not yet have enough forms of energy technologies that could, as a group, provide a carbon-free energy economy at any reasonable cost. Creating that capability should be the mission of an R&D program.

1. Key Points from Climate Science and Global Emissions Scenarios

The key points from climate science and emissions scenarios that are critical to the economic analysis of policy options are:

- Increases in global average temperatures are related to the concentration of greenhouse gases in the atmosphere. Once emitted, greenhouse gases remain in the atmosphere for many decades, so cumulative emissions over a long period of time determine changes in greenhouse gas concentrations. As a result, climate change risk is a function of cumulative greenhouse gas emissions, not emissions in any given year.

- Discussions of long-term objectives for climate policy usually focus on stabilizing greenhouse gas concentrations at some level, so as to limit temperature increases. The concentration of greenhouse gases in the atmosphere will continue to increase as long as there are net additions of greenhouse gases. To achieve stabilization of concentrations and temperature at *any* level will require that average economy-wide greenhouse gas emissions be reduced to nearly zero.
- Given the scale of projected increases in global greenhouse gas emissions, achieving zero net carbon emissions by the middle of the next century will require producing at least as much energy as is now produced from all sources by means of processes that have near-zero net carbon emissions. It is not possible to accomplish this with current technologies at anything close to the current or projected cost of energy produced from oil, natural gas, and coal.
- Within the next decade or two, developing countries will overtake the industrial world in total greenhouse gas emissions, so that by 2025 more than half of global annual emissions of greenhouse gases will be coming from developing countries. Thus no long-term objective of climate policy can be achieved without effective actions to reduce emissions from developing countries. Moreover, comparison of greenhouse gas intensity between developing and industrial countries suggests that there is a large potential for near-term emission reductions in developing countries at costs far lower than comparable emission reductions in the United States and other industrial countries.

These features of the climate problem have some very strong implications for policy design. Since only cumulative emissions over long time periods matter for climate risk, mandatory caps that place specific limits on near-term emissions in each year create significant cost risks without accompanying benefits. Near-term limits on greenhouse gas emissions require the use of current technology for reducing greenhouse gas emissions, and as I will discuss in Section 4, they provide no credible incentive for research and development aimed at wholly new and more affordable technologies.

Nearly-zero greenhouse gas emissions cannot be achieved with current technologies without massive disruption to standards of living. Once technologies are developed that can make massive emissions cuts affordable (even if still quite costly) then it will be possible to "make up for" reductions that we might not undertake today. Therefore the only reductions in emissions that make sense economically until zero-carbon energy becomes affordable as the mainstay of our energy system are those that are very cheap now.[1]

These considerations suggest that the most important long-term feature of any policy initiative is the impact it will have on investment in R&D and the development of new technologies to provide essentially carbon-free energy at an affordable cost. For near-term emission reductions, the most cost-effective emission reductions available today are in developing countries, placing a high priority on near-term control policies to bring about changes in how energy is used in developing countries.

2. Overview of Range of Available Policy Approaches

Proposed approaches for climate change policies that involve a commitment by the government to bring about changes in future greenhouse gas emissions include:

- Pure cap-and-trade
- Cap-and-trade with a safety valve
- Carbon tax
- An R&D-focused "technology strategy"
- Market transformation and technology transfer in developing countries

These policy approaches form a continuum, all of which can be implemented in a market-based manner. At one end of the scale are policy designs that impose specific, rigid limits on greenhouse gas emissions on specified dates. These are the pure cap-and-trade programs, which place a cap on emissions and allow trading of allowances between regulated parties to create an incentive for choice of the most cost-effective mitigation options. Much attention has been paid to these designs, which have been used successfully in other environmental areas such as the Acid Rain program (Title IV) of the Clean Air Act. The McCain/Lieberman amendment to the 2005 Senate Energy Bill (S. 1151) falls in this category.

[1] Their cost should be less than the present value of the cost of "making up" for them when the zero-carbon economy becomes viable. For example, if nearly all GHG emissions could be eliminated or offset at \$25/tonne CO equivalent starting in 2050 (i.e., \$93/tonne carbon-equivalent), then the most that it makes economic sense to pay for emissions reductions in 2010 is about \$3.60/tonne CO_2-eq. (or \$13/tonne carbon-eq.), using a 5% real discount rate.

The rigidity of emission limits is progressively loosened in proposals for combining cap-and-trade with a "safety valve" or for simply using a carbon tax to penalize the use of all fossil fuels in proportion to their carbon content. Both safety valve and carbon tax approaches avoid the imposition of a rigid cap, and instead rely on the economic incentive of putting a price on carbon emissions to achieve changes in emissions levels.

An R&D-focused technology strategy would commit the Federal government to supporting the research to create new technologies whose adoption in the future will enable much larger and more cost-effective emission reductions than are possible today; this also can, and should be designed in a market-based manner.

Thus, even now, the Congress is looking at a continuum of proposals, with the most rigid being the M/L Bill with its specific targets and timetables for near-term reductions, and the least rigid and potentially most cost-effective being a focus on devising and implementing a major and comprehensive R&D program to produce affordable, zero-emitting technology that will be possible to adopt on a massive scale, throughout our economy and that of the globe.

The pure cap-and-trade approach places the highest priority on achieving fixed and predictable emission reductions, and accepts whatever the cost of achieving those emission reductions may be. The pure carbon tax limits the cost of achieving emission reductions to be no greater, per unit of carbon removed, than the tax. The emission reduction achievable from a carbon tax is uncertain, because it depends on how much emission reduction is possible at a cost equal to or less than the tax. Thus the carbon tax places the highest priority on cost containment, while tolerating some uncertainty in the level of emission reductions to be achieved. The safety valve becomes indistinguishable from a carbon tax once the price limit on emission allowances is reached.

Technology policy and policies toward developing countries address the two features of climate policy that are not addressed by mandatory limits on near-term emissions. These, I will suggest, offer far more potential for cost-effective emission reductions in the near and long term, and are appropriate places for Congress to consider immediate action.

This Congress has considered proposals in four out of these five categories. The proposed McCain/Lieberman amendment to the Senate Energy Bill of 2005 fell in the first category, of mandatory caps. Proposals by the National Commission on Energy Policy (NCEP) and Senator Bingaman (S.A. 868) fall into the second, safety valve, category. An approach to reducing emissions from developing countries was passed into law as Title XVI of the Energy Policy Act of 2005, along with some of the elements of a technology strategy. Only carbon taxes per se are not talked about in Washington, but the choice between carbon caps and carbon taxes is a very important one in the literature on climate policy.

I do not believe it is appropriate to narrow consideration at this time to only "mandatory" programs in the sense of binding caps on specific schedules, which if taken literally would include only the McCain/Lieberman proposal. Although used and justifiable in other environmental areas, this is not the most suitable policy design for climate change. Costs of large near-term reductions are high, mandatory caps create large risks and uncertainty about cost, and even mandatory caps cannot provide a credible incentive for R&D to develop needed technologies. Safety valve proposals, which become indistinguishable from carbon taxes once the safety valve becomes effective, offer additional flexibility and need not imply greater climate risks.

Therefore, I would encourage you to include in your thinking about "mandatory" programs all policies that force households and businesses to take into account a cost of greenhouse gas emissions. This would recognize that carbon taxes, as well as the NCEP and Senator Bingaman's approaches, are all "mandatory" approaches to emissions reductions.

However, none of the mandatory programs aimed at putting limits on future carbon emissions will provide a credible incentive for R&D or actions by developing countries. Such mandatory programs are not the only actions that can be taken today. I have concluded that commitments to support technology development and bring about change in the rate of growth of emissions from developing countries are a more effective and appropriate focus for current action on climate policy. To my mind, it makes the most economic sense to start where resources committed to mitigation of climate change can achieve the greatest gains, considering both near-term and long-term outcomes as a whole. Therefore, we should start with a clearly articulated and carefully implemented R&D program for developing affordable zero-carbon emitting technologies. Neither the technologies nor the necessary R&D program to create them presently exists.

The first three approaches (pure cap-and-trade, cap-and-trade with a safety valve, and carbon taxes) all function by placing a direct price on GHG emissions. In the next section, I will discuss each of the individually, highlighting their respective strengths and weaknesses. I will then provide comparisons of the outcomes under a pure cap-and-trade proposal (i.e., the McCain/Lieberman proposal) to those of a proposal that directly limits costs rather than emissions (i.e., the GHG cap program of the Bingaman/NCEP proposal) to highlight how they tend to differ in their impacts. I complete the next section by addressing a number of issues related to allocation of allowances that I feel are greatly misunderstood, yet extremely important if a cap-and-trade approach is selected instead of a carbon tax approach for imposing a price on carbon emissions. The following, and last section, will then turn to an important limitation of all approaches that directly price emissions in the unique situation of climate change policy, and the reasons that an R&D-focused technology strategy needs to be the first and foremost consideration in any policy to address climate change risks. It is my view that none of the proposed policies to date properly address this R&D need. In general, they have confused subsidies with the need for R&D on new technologies, and for the most part the subsidy programs that have been proposed are also unnecessary for motivating a least-cost response under a carbon-pricing program.

3. Approaches that Place a Direct Price on Emissions

A. Pure cap-and-trade with rigid emission limits

Emission caps are enforced, under cap-and-trade proposals, by distributing a set of emission allowances, limited to the quantitative cap. These emission allowances can be traded, so that emission reductions will occur where they are most cost-effective given current technology. The cost of a cap-and-trade program depends on how tightly the caps are set initially and how they are tightened over time. How emission allowances are distributed also affects the overall economic impact of this policy approach.

Near-term caps, such as those proposed by Senators McCain and Lieberman, can only be met through use of costly measures based on today's technology. This raises their costs substantially compared to a policy sequence in which new and more affordable technologies are developed first, so that much larger emission reductions can be achieved at much lower cost.

Emission caps, even if never tightened, will become more expensive over time, because energy needs are always growing as population increases and the economy expands. Holding greenhouse gas emissions constant in the face of ever-increasing energy demand requires going to ever more costly control options. The depth of the cuts required can be seen by comparing business-as-usual, or current-policy emissions to emissions under the cap. Based on the current EIA Annual Energy Outlook forecast for emissions under current policies, the limits proposed by Senators McCain and Lieberman would require total CO_2 emissions from covered sectors to be reduced to 15% below current policy levels in 2010 and 26% below current policy levels in 2020. Continuing the McCain/Lieberman cap to 2050 would require a reduction of emissions to 48% below current policy levels in that year. Tightening the cap to a level consistent with current proposals for programs that could stabilize greenhouse gas concentrations in the atmosphere would require emissions to be reduced to more than 80% below what CRA International projects for current policy emissions in 2050.

The imposition of rigid limits creates unnecessary cost risks, even in the near-term, because rigid limits can become very expensive if economic growth exceeds expectations or if costs of measures required to reduce emissions turn out to be higher than assumed. Since climate risks are not affected by variations in emissions from one year to the next, but only by cumulative emissions over long time periods, these cost risks associated with rigid caps are completely unnecessary to achieving long-term climate goals.

The perception that fixed caps create excessive cost risks is, I believe, widely shared. The McCain/Lieberman amendment would have created specific fixed and mandatory caps. Other policy approaches before Congress are based on a recognition that setting this kind of mandatory cap is not the only way to take effective action to address climate change. All the other approaches before the Congress involve market based incentives, but do not place a rigid cap on emissions. These approaches are more suitable to the nature of the climate problem.

B. Cap-and-trade with a safety valve

Combining cap-and-trade with a safety valve has the purpose of reducing the cost risk associated with the pure cap-and-trade approach. Senator Bingaman and NCEP's proposals also reflect a concept called an "intensity-based" cap, but this only serves to reduce the expected costs of the policy. The real reason that these proposals have reduced risk of unexpectedly (and unacceptably) high costs lies wholly in the safety valve provision.

The original concept of an "intensity-based" target is that caps would only be tightened in relation to economic activity levels. If economic activity is high, an intensity approach would allow a somewhat looser cap to accommodate the extra need for energy, rather than to choke it off by having a rigid cap no matter what the level of economic activity. However, as implemented in these two current proposals, the "intensity-based" cap would, in fact, still be an absolute cap, computed up to ten years in advance and rigid thereafter. Its primary novelty is that by computing a cap that is tied to economic growth rather than historical outcomes, it would more gradually phase in the cap's apparent stringency. This certainly makes such a cap less costly than a tighter cap that prevents any further emissions growth at all. However, as long as the cap is binding at all (which is the intention), there is still uncertainty on how costly it will actually be to attain, especially given its rigidity over ten-year periods. (A cap that is truly flexible from year to year in response to economic activity outcomes might somewhat mitigate this cost uncertainty, but would require continual, year-to-year updating of allocations. This updating would probably be more detrimental than helpful in producing compliance planning certainty, while still not assuring that costs of control would remain below some planned level.)

Nevertheless, the Bingaman and NCEP proposals do have much less cost risk than previous cap-and-trade proposals, entirely due to the safety valve provision. The safety valve places a ceiling on the price of carbon allowances under the cap provision. This would be accomplished by allowing companies to achieve compliance by paying the safety valve price to the government in lieu of turning in actual allowances that have been issued. Alternatively, the government could issue more allowances at the safety valve price, which would then be turned in along with originally-issued allowances. Either way, the effect of the safety valve is to make the cap itself flexible rather than rigid. However, its flexibility is linked to the cost of control rather than to economic activity per se.

In summary, the safety valve is a very important way of minimizing cost risk under a carbon emissions control policy, and it does so by converting the carbon cap into a carbon tax if the cost of control to meet the cap is higher than the pre-agreed safety valve price. By design (and also just like a tax), this can alter the amount of emission reduction that is achieved, thus making emissions reductions uncertain instead.

C. Carbon taxes

Once the safety valve becomes effective, the environmental outcomes and control costs under a program based on safety valves become indistinguishable from a carbon tax. However, a carbon tax policy would avoid creating the costs and bureaucracy associated with allocating allowances and administering an emission trading and enforcement system.

All of these approaches—rigid caps, caps with safety valve, and carbon taxes—share a common feature of mandatory but market-based emission limitation. They require an emitter to pay for its legal emissions, either by purchasing an allowance, foregoing revenues from the sale of an allowance it was allocated, or paying a tax. Each creates revenues, and the choice must be made in designing the policy of who will collect these revenues and how they will be used. This is the choice between auction and allocation of allowances under a cap-and-trade system.

The safety valve involves the sale of emission allowances for a fixed price. It is equivalent to charging a carbon tax on the use of fossil fuels, with the tax rate set for each fuel based on its carbon content. Use of a carbon tax would also leave control of how to use the revenues under the normal budget process. In contrast, revenues from auctioning allowances or from selling allowances under a safety valve can be placed outside the budget process, as they are in both the McCain-Lieberman and Bingaman proposals. Using a free allocation of carbon allowances to compensate some of those harmed by the imposition of limits on greenhouse gas emissions is also a use of potential revenues that could accrue to the government, and removes decisions about that use of revenues from the normal budget and authorization and appropriation process. This has a very important influence on overall economic costs.

The proposed cap-and-trade and safety valve programs are likely to impose higher costs than a carbon tax. In part, this is true because they are likely to have greater administrative costs than an explicit tax. But more importantly, by taking revenues outside the normal budget process, these policy designs eliminate the possibility of using some or all of the revenues to replace taxes that would otherwise have to be raised through other federal tax programs. As I discuss in subsection E below, not allowing revenues from allowance auctions to be used to offset impacts of emission limitations on total government revenues substantially increases the cost of the Bingaman and McCain/Lieberman approaches.

Otherwise, the effects of cap-and-trade with a safety valve and a carbon tax are indistinguishable. Consumers of energy will experience increases in the cost of energy, in one case by the price that energy producers must pay for carbon allowances and the other by the carbon tax they must pay. The response of businesses and households to these altered prices will be identical. Differences will arise only from how potential revenues from the safety valve or carbon tax are utilized.

D. Analysis of the costs of mandatory caps and safety valves

In order to quantify the costs and emission impacts of the McCain/Lieberman and Bingaman amendments, my colleagues and I have used CRA's Multi-Region National Model of the U.S. economy.[2] This model has been used in a variety of studies over the past 10 years, and was used by the National Commission on Energy Policy in its own analysis of the economic impacts of its proposals.

We have analyzed a range of estimates for the impacts of the McCain/Lieberman proposal (M/L) and of the carbon cap program in the Bingaman Amendment (BA). For M/L our range was based on assumptions about the cost at which a carbon free "backstop" technology will become available and how that cost will drop over time; the availability and cost of "offsets" to CO_2 emissions in covered sectors; and the choices that will be made about long-term emission limits after 2020. For the BA, at the low end of the range, we assume that regulated non-CO_2 GHGs are able to be costlessly reduced up to the point where the marginal cost of reducing those other GHGs exceeds the safety valve price, based on marginal abatement cost curves prepared by MIT. At the high end of the range, we assume that non-CO_2 GHGs are reduced costlessly only up to the point where they achieve their own share of the intensity targets. Our baseline or "current policy" emissions trajectory was based on the AEO 2005 reference case forecast of CO_2 emissions, and was not varied, though this would be another source of cost uncertainty, especially for the M/L rigid caps.

The form of Senator Bingaman's carbon cap proposal that we analyzed sets a cap on greenhouse gas (GHG) emissions from 2010 onward. The cap is to be calculated in 2006 so that it will cause greenhouse gas intensity (GHG emissions divided by GDP) to fall by 2.4% per year from 2010 to 2020, and then to fall by 2.8% per year thereafter. The required improvements in GHG intensity are converted to fixed caps for the next decade by multiplying the required GHG intensity times the level of GDP in each year that is projected as of 2006.

We applied a "safety valve" which allows regulated entities to purchase carbon allowances for a price of $7 per ton of CO_2 in 2010, escalating at 5% per year (nominal). Both the safety valve escalation and the annual improvement in GHG intensity can be revised by joint resolution. The bill requires the President to report to Congress on what other countries are doing to reduce GHG emissions as a basis for recommending such revisions. The proposal includes some, but not all, emissions of non-CO_2 GHGs in the calculation of GHG intensity and allows banking of allowances for use in future years.

We assumed that under Senator Bingaman's proposal a large fraction of carbon allowances will be "allocated" to businesses that face disproportionately large negative impacts, and that 5% in 2010, rising to 10% by 2020, of the allowances will be auctioned to provide funding for subsidies for the development and deployment of selected energy technologies.

Sources of economic impacts. Economic impacts arise from four major sources. Direct costs of complying with emission limitations or of adjusting energy supply and use in response to a safety valve/carbon tax are incurred by energy producers and consumers. These costs arise from the necessity of diverting resources from other productive uses to reducing greenhouse gas emissions. The activities involved include substituting more costly but lower carbon forms of energy for fossil fuels, making investments and incurring higher costs to improve energy efficiency, and losing the benefits of foregone energy services.

A second set of costs arises from an increased excess burden of existing taxes. Both the Bingaman and M/L proposals provide for allocations of allowances and specify how revenues from allowance auctions will be utilized. They do not allow proceeds to be used to reduce other taxes. It is widely accepted among economists who study the Federal tax system that the current set of income, payroll and corporate taxes impose a deadweight loss on the U.S. economy. It has been found in

[2] For documentation of the MRN model, see *http://www.crai.com/pubs/pub__3694.pdf.*

a number of studies that a system of emission limits or carbon taxes that raises energy costs effectively increases the burden of existing taxes on the economy.[3] Using the revenues from sale of carbon allowances or from a carbon tax to substitute for revenues that would otherwise be raised through conventional taxes can reduce or eliminate this distortion. Allocating emission allowances at no cost removes that ability to reduce the distortions of the tax system and contributes to higher costs, as does reserving revenues for new spending programs that are created by the policy.

CRA's analyses have revealed a need for governments to use allowance auctions under a GHG cap to generate a certain amount of new government revenue to offset likely reductions in existing tax revenues due to a decline in economic activity from the cost of the policy. If such offsetting revenues are not tapped from the value of the allowances, then governments will either have to cut services or else raise existing tax rates. The latter action would actually exacerbate the costs of the policy, and thereby create an inefficiency due to tax distortions even while the carbon allowance market may function in a perfectly efficient manner in achieving cost-effective emissions reductions to meet the cap. Neither of the proposals analyzed provides for any revenues to be used to offset tax base erosion.[4] Although there are some revenues from auctions and safety valve sales, these revenue sources are earmarked for new spending programs rather than to supplement other, falling sources of government revenues.

A third cost element arises from the transition costs of job search which are triggered by the changes in real wages and shift in industry structure causes by emission limits or safety valve/carbon tax policies. This cost element shows up directly in the results as an increase in transitional unemployment, and contributes to reduced GDP and to lower household consumption and welfare.

Finally, since MRN is a fully dynamic computable general equilibrium model with forward-looking expectations, the prospect of rising carbon allowance prices and future economic impacts leads households to change their current saving and investment behavior. Households reduce their current consumption, in order to save and provide for higher future income to cover the increasing costs of tighter emission limits and rising safety valve/carbon taxes. This anticipatory behavior makes future costs show up in the present. The banking option included in both M/L and BA also encourages businesses to undertake emission reductions in early years in excess of those required by carbon limits, in order to avoid even higher future mitigation costs due to tightening emission limits or higher safety valve/carbon taxes. This also contributes to costs in early years.

I provide details of our comparison of the impacts of M/L and BA in Exhibits 1-4* at the end of this testimony. Generally speaking, our results suggest that M/L impacts are about 3 to 4 times larger than the impacts for the BA cap program. Key economic indicators all follow this pattern:

- For 2010, the GDP loss under BA would be about $21 billion to $34 billion, or a 0.1% to 0.2% reduction (compared to 0.3% to 1.0% for MIL). The GDP loss increases over time, both because the percent impact of BA increases with time, and because GDP increases with time.
- GDP loss under BA in 2020 is $70 billion to $96 billion. (This compares to $214 to $517 billion for M/L) It reflects a 0.3% to 0.4% reduction in 2020 GDP (compared to 0.8% to 1.9% for M/L).
- Per household consumption losses under BA are $135 to $147 in 2010 and $147 to $164 in 2020. (Comparable M/L losses are in the $450 to $800 range.)
- Job losses under BA in 2020 are 281,000 to 326,000 (compared to 793,000 to 1,306,000 under M/L).
- Reduction in coal output in 2020 is 8% to 11% (compared to 23% to 42% for M/L).
- Reduction in refined oil output in 2020 is 2% (compared to 6%-13% for M/L).

[3] On the issue of how existing tax distortions are magnified by emission limits, see Larry Goulder, Ian Parry and Dallas Burtraw, "Revenue-Raising vs. Other Approaches to Environmental Protection: The Critical Significance of Pre-Existing Tax Distortions," RAND Journal of Economics, Winter 1997; and Larry Goulder and Lans Bovenberg, "Optimal Environmental Taxation in the Presence of Other Taxes: General Equilibrium Analyses," American Economic Review, September, 1996.

[4] In very approximate-terms, the share of the allowances that the government would need to offset tax base erosion and thus avoid exacerbating policy costs appears to be between 30% and 60%. This is based on multiple scenarios analyzed by CRA International using its MRN model, and apparently has been corroborated by analyses by Prof. Goulder of Stanford University (personal communication).

* The exhibits have been retained in committee files.

- Carbon prices are $13 to $18/tonne C in 2010 and $21 to 29/tonne C in 2020. (M/L carbon prices are $47-$130 in 2010 and $75-$209 in 2020.)
- Under BA, carbon allowance prices hit the safety valve price in 2020 in the high case and 2035 in the low case.

The greater cost certainty associated with the safety valve is apparent in the fact that our M/L cost ranges are much wider than those we estimated for the BA cap. However, the lower overall costs of the BA cap simply reflect the fact that it imposes a much less stringent demand for near-term emissions reductions. Over the period from 2020 to 2050 BA provides emission reductions that total between one-third and two-fifths (32% to 40%) of those provided by M/L. Since the costs of BA range from 25% to 33% of M/L, the comparison also illustrates the law of diminishing returns, in that it costs proportionately more to achieve the larger emission reductions required by M/L.

E. Issues in allocating allowances

Allocations versus auctions. I understand the committee is very interested in the issue of allocation of allowances under Senator Bingaman's proposal. This is a feature of policy design for which there are several alternatives. Senator Bingaman distinguishes between auction and allocation. Some allowances would be allocated to parties that suffer disproportionate harm from emission limits, and some would be auctioned and provide revenues.

The first question that the Committee might want to consider is who should control the use of the revenues from any auctioned or safety valve allowances. If revenues are placed in the general fund, then Congress will retain the ability to make the decisions about how the revenues will be utilized. This will allow Congress to consider all societal needs together, and to balance competing needs as they evolve. To place the proceeds into a Trust Fund that earmarks them for spending only related to climate policy is tantamount to deciding now that climate-related spending needs to be separated from all other government spending decisions, and given a separate, more elevated priority than all other societal needs, including future needs that may not be anticipated at present. Public finance practitioners generally frown on the idea of earmarking funds from particular revenue sources to particular purposes, because the amount of money that will be collected from a particular source is only connected loosely, if at all, to the amount that it is wise to spend on even a related purpose. Thus earmarking is likely to produce either too much or too little funding, and it removes the decision about how much should be spent from the normal budget, authorization, and appropriation process.

In this regard, I also note that free allocation of allowances is not the only way to provide for compensation of affected parties. Any compensation that can be achieved by a free allocation formula could, in principle, be replicated under a 100% auction—it would only require that the auction revenues be returned to companies by the same formula that would have been used for allocations. Funds could be appropriated to provide compensation for those disproportionately harmed, or specific tax credits could be enacted. Determining how to make this compensation using normal budget processes would be no harder than determining how to allocate allowances under the procedures outlined in Senator Bingaman's proposal.

While general principles of public finance suggest that separation of revenues from such a policy into a Trust Fund is probably unwise, my personal research has found that such an approach also could exacerbate the total costs of any carbon-pricing policy, and thus would be inconsistent with principles of minimizing policy costs. Paradoxically, allocating all of the allowances at no cost to affected parties, and/or using all of the proceeds from sale of allowances to fund new spending programs, can lead to far larger costs to the economy than necessary. This policy cost inflation can be averted by using some allowance or carbon tax revenues to replace other taxes that would have to be raised to meet budget targets. By allowing carbon policy revenues to flow to the general fund, Congress retains its ability to determine how much of the proceeds from allowance sales or carbon taxes should be used for replacement of other tax revenues that can be expected to decline under the carbon policy.

Free allocations cannot compensate all businesses and households. Impacts on households and industry are not determined by where regulations are put in place. An upstream system like that in Senator Bingaman's proposal still imposes costs on households and industries. Not all the costs are borne by fuel suppliers, even if they are the point of regulation. All users of energy have higher production costs. Some will be able to pass some of these costs to their consumers, while others will have little ability to pass costs through, and the brunt of the financial impact will be borne by their shareholders. In the end, households cannot pass the costs on to anybody, and they ultimately bear the entire cost, as consumers of higher cost of goods and services, and as shareholders in companies that cannot pass the costs on.

Conceptually, allocations could be used to help compensate the companies that bear an exceptional and unfair burden. We have, in other contexts, estimated the average loss in capital value to owners of assets in aggregated economic sectors such as the oil, gas, coal and electricity generation sectors. However, there is no simple formula to identify exactly which companies these are, or what amount of allocation would actually provide for an equitable burden sharing arrangement. Companies within the same economic sector may face diverse impacts, so that an estimate of the "average" loss of profitability for each sector may bear no correlation to the sum of losses across the negatively affected companies within each sector. Even if one could identify reasonable allocations to each sector of the economy, comparable allocations to each company within a sector would have little chance of equalizing burdens within the sector. Attempts to analytically identify company-specific burdens within a sector would be even more challenging than attempts to identify needs by sector, as the relevant data are not even publicly available. Thus, the idealized concept of mitigating the impact of the rule on individual companies cannot be estimated quantitatively at the level of detail needed to define company-level allocations, let alone be condensed to a relatively simple formula.

It is also important to realize that the energy sectors (including non-regulated entities in the energy sectors) are not the only sectors that will bear losses of capital value as a result of a carbon pricing policy. All sectors of the economy will be affected to some degree, as all are consumers of energy to varying degrees. As more and more of the needs to be compensated are recognized, the identification of a "fair" allocations rule will become exceedingly complex.

More importantly, once it is recognized that needs for compensation include all individual energy consumers, and not just companies, policy makers will have to realize that it is not possible to offset losses for everyone through allocations of allowances. The total cost of a cap-and-trade system will always exceed the total value of the allowances in that system:

- This is because companies must pay (1) to reduce emissions down to the level of the cap and also (2) for every ton of emissions that remains after meeting the cap. The value of the allowances equals only the second component of total costs. At most, the government can give that entire value back to the companies by free allocation of 100% of the allowances, but that leaves companies still incurring the first cost component, and without any way to compensate them for that cost—which is the real net cost to society.
- It is true that companies may be able to pass some of these two cost components on to their customers, and so directly-regulated companies could be given more compensation than the cost that their shareholders bear if all of the allowances were allocated to them alone. However, this only means that a part of the net cost has been spread to other, non-regulated parties, including consumers. They, in turn, would require their share of the allowance allocation to be compensated for the part of the cost that was passed to them. There is not enough value in the allowances to cover all costs to regulated companies if they cannot pass those costs on, and neither can that value cover all the incurred costs after they are divided up and spread throughout the entire economy.

Thus, a carbon pricing policy will always impose a real net cost on the economy that cannot be eliminated through any allocation formula that may be devised. All that an allocation scheme can do is alter the companies and individual consumers that end up bearing the burden of that cost.

These challenges in identifying fair allocations are not a result of proposing an upstream point of compliance. They would be equally difficult under any downstream or hybrid form of implementation. They do, however, present more prominent issues when using a cap-and-trade approach than under a carbon tax, because the former system does require that a specific decision be made for how to distribute the allowances. (At the same time, needs for compensation and burden sharing would also exist under a carbon tax, and there would also be equivalent degrees of ability to achieve such compensation under a carbon tax.)

Administrative costs and bureaucracy for small and distant emission reductions. I have estimated that under Senator Bingaman's proposal, the price of carbon allowances would rise above the safety valve level between 2020 and 2035. EIA puts this somewhat earlier.

This effectively turns the Bingaman proposal into a carbon tax program, but with the much higher costs of an administrative apparatus for issuing, enforcing, and trading carbon allowances that doesn't actually do anything other than impose a pre-determined price on carbon emissions.

This leads to the question of whether it is desirable to create the bureaucracy and administrative burden of a comprehensive national emission trading program for the small reductions that are possible with a safety valve. The main differences between safety valve proposals and simply establishing a federal fuels tax based on carbon content are (1) that the safety valve has a greater administrative burden, and (2) the safety valve approach allows revenues that would otherwise go into the normal budget process to be handed out by an executive agency or quasi-government corporation.

Thus the government cedes the ability to set overall social priorities for the use of the funds. Further, it sets the stage for automatically spending whatever is collected on climate-related technologies, without regard to the need for spending at such a level. Because it is not tied to an R&D program with clearly specified goals and a plan for meeting those goals, much of the spending is likely to result in subsidies on investments that would occur anyway (because they are cost-effective under the carbon price) or on investments that are not desirable (because they are only feasible at a cost that is higher than the safety valve price, which by definition reflects the maximum that is deemed reasonable to spend on near-term emissions reductions).[5] The use of an outside entity does not solve the problem of creating a good R&D program; but it does mean that Congress loses the opportunity to make those R&D spending decisions directly and transparently.

4. The Need for R&D Strategy to Be the Leading Edge of Climate Policy

A. New technology is not encouraged by mandatory limits

Although M/L has much more substantial (and uncertain) costs than the BA cap proposal, both proposals have substantial costs. But despite these costs to the economy, neither fixed caps nor safety valve/carbon tax policy designs can provide an adequate incentive for the critical piece of the solution—which is creation of radically new technologies. In my opinion, it would be better now to put resources into developing new technologies than in forcing the use of existing technology to achieve relatively small and costly emission reductions. Creating an effective R&D program will not be cheap, but it ultimately has to happen if climate risks are to be reduced. The difficult decisions are how much to spend now, and how to design programs to stimulate R&D that avoid mistakes of the past.

The subsidies to current technology embodied in BA and M/L are not likely to bring about that change in the fundamental direction of R&D, because they are directed at the demonstration and use of current technology. These subsidies should be carefully distinguished from funding for R&D. Most subsidies would be unnecessary under a carbon-pricing program, as the market price of carbon due to the cap provides the appropriate financial incentives for the optimal use of the control methods that would then also benefit from the subsidies. A well-designed policy to address needs for R&D in entirely new technologies is needed, not subsidies to get existing technologies deployed in the market place. A very different commitment is needed to create programs that will change the direction of basic research toward creation of climate friendly, zero carbon technologies. Subsidies for demonstration and use of currently available technologies do not create incentives for creation of entirely new technologies.

In BA, the carbon intensity basis for mandatory caps ensures that they rise gradually, so that there is little change in emissions for the next decade. The safety valve, by design, takes over from the mandatory cap when its costs begin to rise. By design, the safety valve will not stimulate the desired level of R&D. By attempting to limit cost to a level deemed tolerable, it eliminates adequate incentives for R&D on new technology.

Nor will an adequate incentive be provided if the safety valve were eliminated, now or in the future. This would provide a trajectory of rising allowance prices and tightening limits. But those future policy results cannot be a credible incentive for current R&D, as I explain next.

B. Carbon pricing programs cannot provide credible incentives for technology development

Whether cap-and-trade or a carbon tax is the policy approach taken, these mandatory programs cannot achieve the most important need in a climate program, which

[5] Nuclear power presents a different situation. Although the technology is nearly zero-emitting (there are some emissions associated with its fuel cycle), available now, and cost-effective under even a modest carbon pricing scheme, its deployment is hampered by existing policy. Removal of institutional and political barriers to new nuclear generation might be the most important way of enabling existing nuclear generation technology to provide cost-effective emissions reductions within the next two decades.

is to stimulate development of the kinds of technologies that alone can make significant mitigation of climate risk possible in the long run.

Emission caps are not only premature and risky for the economy. They are not capable of stimulating the kind of technology development that is an absolute necessity to achieve any of the objectives of climate policy. Putting a stop to the continued growth of greenhouse gas concentrations in the atmosphere requires meeting all of today's energy needs in a way that produces zero net carbon emissions, and does so at acceptable cost. That is not possible with the set of technologies that exist today.

Hoffert *et al.* argue that "the most effective way to reduce CO_2 emissions with economic growth and equity is to develop revolutionary changes in the technology of energy production, distribution, storage and conversion."[6] They go on to identify an entire portfolio of technologies, suggesting that the solution will lie in achieving advances in more than one of the following categories of research:

- wind, solar and biomass
- nuclear fission
- nuclear fusion
- hydrogen fuel cells
- energy efficiency
- carbon sequestration

Currently available technologies cannot provide sufficient or low cost reductions to meet the GHG challenge. Developing that supply will require basic science and fundamental breakthroughs in a number of disciplines. The magnitude of possible reductions in the next decade or two achievable with today's technology is dwarfed by the magnitude of reductions that successful innovation would supply through these routes.[7]

Emission caps cannot provide adequate incentives. Even combined with an allowance trading system that puts a price on emissions, fixed caps cannot provide the incentives for the necessary technological change to occur. Thus, efforts to address climate change by imposing costly caps or taxes in the near-term will fail to provide long-term reductions. Additionally, if the R&D externality is being effectively addressed, implementation today of a cap or tax that will not become stringent until a later date will provide little or no further benefit in the form of an "announcement effect." The only role for near-term GHG caps or taxes would be to achieve emissions reductions that are justifiable immediately because their cost per ton removed is less than the present value of the cost of avoided future emission reductions that would come from the future technologies, once they become available. Any other degree of stringency is unwarranted before R&D is successful, and unnecessary to supplement policies that will address the fundamental market failures associated with R&D.

Announcements of high future carbon prices to stimulate R&D are not credible, because those carbon prices would not be necessary once technologies are developed.[8] When new technology and new capacity investments are the issue, the only policy strategies that matter immediately are those that will increase incentives to invest in R&D, and direct the R&D toward technologies that will create a much larger supply of carbon-free energy alternatives at acceptable costs. Therefore, the only attribute of a cap-and-trade program that will matter will be the future course of the cap and its implications for future allowance prices.

None of the "mandatory" programs under consideration could stimulate the kind of R&D in new energy technologies that is required. The "safety valve" in the NCEP program and Senator Bingaman's amendment is designed to provide assurance that the price of emission allowances will not reach economically unsustainable levels. But that policy design causes the prices to be set at a level far too low to provide an adequate incentive for private investors to develop radically new technologies.

To motivate the large R&D investments required, it would be necessary for governments to announce policies that will lead to high enough implicit taxes on carbon

[6] M.I. Hoffert et al., "Advanced Technology Paths to Global Climate Stability: Energy for a Greenhouse Planet" Science, Vol. 298, Nov. 1, 2002, p.981.

[7] For example, if all of the existing U.S. natural gas-fired combined cycle generating capacity were to suddenly be fully utilized, we estimate based on our models of the U.S. power sector that current annual U.S. CO_2 emissions would be reduced by about 80 MMTC—about a 4% reduction in total U.S. GHG emissions—and it would come at a cost of about $80/tonne C, even if gas prices would not be inflated by the sudden surge in natural gas demand.

[8] These points are developed in a more rigorous fashion in W.D. Montgomery and Anne E. Smith "Price, Quantity and Technology Strategies for Climate Change Policy." To appear in Human-Induced Climate Change: An Interdisciplinary Assessment, Cambridge University Press, forthcoming 2005.

emissions to provide an adequate expected return on R&D investment. This tax will necessarily exceed the tax needed to induce adoption of the technology once it is developed. Once affordable technologies are produced, a relatively low carbon tax price will be enough to motivate companies to adopt the new technologies. That lower carbon price will not be enough to compensate the investors who paid for the R&D, but it will be enough to get it utilized.

Even if laws passed today served to announce a future emissions tax high enough to create such an incentive, no future Congress or Administration would keep that commitment once the technology was developed. As in the case of patents, there is a tradeoff between efficiency in resource allocation and providing an incentive for R&D. A carbon price above the level necessary to induce adoption of the new technology will cause avoidable deadweight losses as all energy supply and use decisions are distorted. Reducing implicit carbon taxes to the lowest possible level to get the new technology deployed will always be beneficial to the economy. Therefore, future governments will face irresistible pressure to let the implicit tax on carbon emissions fall back to a level just sufficient to get the R&D utilized, taking away all the rewards to innovation.

This leads to a fundamental dynamic inconsistency that makes any effort to set emission caps or announce future carbon prices sufficient to stimulate R&D not credible. Since private investors can understand this is the optimal strategy for government—and indeed would likely be skeptical of the political ability of any government to proceed with what will look like "corporate welfare"—they will not be motivated to invest in R&D by any announcement of future climate policy.

C. Design of technology policy

What this argument demonstrates is that it is not possible to rely on caps on future emissions, or on announcements of a safety valve or carbon tax, to motivate R&D to develop the new technologies needed for long-term reduction of climate risk. This means that there is an extraordinarily high priority to designing effective programs to stimulate that R&D through incentives provided today. I would urge Congress to turn its interest in climate policy toward a subject it knows well—how to craft a program that will lead to effective use of private and government funds to carry out the R&D needed to provide the radically new technologies required to stabilize concentrations of greenhouse gases and ultimately, global climate.

D. Large opportunities for near-term emission reductions exist in developing countries

For near-term emission reductions, developing countries offer far larger and more cost-effective opportunity for emission reduction that mandatory emission limits on U.S. businesses and consumers. There are a number of ways in which the U.S. Congress could act to increase technology transfer and encourage foreign investment in developing countries, and these actions could lead to near-term reductions in emission larger than any of the mandatory limits on U.S. emissions under considerations.

The provisions of the McCain/Lieberman and Bingaman Amendment proposals dealing with developing countries create no mechanism for bringing about changes in those countries. A great deal of the difference in greenhouse gas intensity between developing countries and industrial countries can be explained by fundamental failures of markets and institutions in developing countries. Much more cost-effective emission reductions are possible in the near-term through programs directed at developing countries by focusing on fundamental institutional and market reforms to create the property rights and investment climate required for private foreign direct investment and technology transfer.[9] These needs are already a focus of the Climate Change Title (Title XVI) of the Energy Policy Act of 2005, which passed into law after the Bingaman Amendment was released. I believe that approach of Title XVI should be followed, and further enhanced if necessary. The more general and less focused provisions expressed in the Bingaman Amendment proposal are unnecessary additions, and could distract from implementing the more focused provisions that already exist as law.

The CHAIRMAN. Thank you very much, doctor.
Mr. Grumet.

[9] Such policies are discussed at greater length in W. David Montgomery & Sugandha D. Tuladhar, "Impact Of Economic Liberalization On GHG Emission Trends In India," Climate Policy Center, May, 2005.

STATEMENT OF JASON S. GRUMET, EXECUTIVE DIRECTOR, NATIONAL COMMISSION ON ENERGY POLICY

Mr. GRUMET. Thank you, Mr. Chairman. My name is Jason Grumet and on behalf of our bipartisan membership of our Commission I want to thank you. I want to thank Senator Bingaman and the rest of the committee for the attention you have given to this issue and our proposal—why do I not start again.

What you missed, Mr. Chairman, was largely me thanking you, so I would like to repeat that if I might, which was to thank you for the attention that you brought to this topic and our proposal and also for having not only the hearing on climate science, but this follow-up hearing.

Let me just begin by directly embracing I think the way that you laid out the criteria for success, because I think we agree fundamentally that the details are very important, that this is not easy, that to succeed we must establish a program that is going to achieve the greatest reduction at the lowest cost. It must be economically efficient, it must be fair, it must protect our economic vitality, our economic competitiveness. It must also instill the desire for a global and truly effective solution.

These are the criteria, Mr. Chairman, that I think are clearly expressed in the sense of the Senate resolution. They are also the criteria which explicitly animated the Energy Commission's policy approach of trying to combine a modest carbon price and augment that with the technology incentives that could bring technologies forward in a timeframe that this challenge requires.

Now I want to just talk for a moment about our overall architecture and then move to the costs and benefits of our proposal. By and large, our goal was to establish a robust architecture that could evolve over time as our understanding of science progresses, as actions of other countries progress, but explicitly to establish a modest initial cost. We achieve that by suggesting a mandatory economy-wide system of market-based regulations. The goal there is to maximize efficiency and also to encourage the private sector to innovate, which of course we have found is always the ultimate solution to these kinds of challenges.

Equally important, Mr. Chairman, we propose a very gradual reduction target and we propose a cost certain, cost cap, to protect our economy against uncertainties that I think we all fear.

Finally, we believe that a modest carbon price, of course, is not in and of itself going to be adequate to bring forth these technologies and we explicitly propose to augment this modest market-based system with a continued active effort on the part of government to advance these technologies.

Finally, we propose that our policy be explicitly linked to the actions of our key trade partners, China, India, and developing countries.

Now let me turn, as this is an economically focused hearing, to the costs and benefits. I would suggest to you that there is actually surprising agreement on the costs of our proposal. Dr. Smith and Dr. Montgomery of Charles River Associates provided the economic modeling that we used in our report to express our sense of the projected costs and benefits and caused us to conclude that we thought the benefits were quite modest. Dr. Gruenspecht and the good people at EIA have done a follow-up analysis which in many ways has eclipsed our own.

Just let me try to put this in perspective, because the economy is a very big place, so very small effects taken out of context can be somewhat misleading. The EIA suggests that due to the imposition of our mandatory economy-wide carbon program gross domestic product in the United States between 2005 and 2025 will grow by 80.6 percent as opposed to 80.8 percent. If I can pull my favorite quote out of the report—and Dr. Gruenspecht, they are practiced in not using adjectives, but I found this quote helpful. It says: “The overall growth rate of the economy between 2003 and 2025 in terms of both real and potential GDP is not materially affected by the commission proposal.”

Put another way, Mr. Chairman, our Nation will be as wealthy on January 15, 2025, as we would otherwise be on January 1, 2025, as a result of the costs of this program.

Now, the numbers I agree are less, I think, instructive than the overall frame, and simply I would suggest that the dire suggestions of economic impacts that have framed our Kyoto debate simply do not obtain here. Coal is not driven from the economy. Coal use in fact continues to increase, as Dr. Gruenspecht said, part of the reason why the United Mine Workers have endorsed this proposal. Natural gas demand does not skyrocket. In fact, as Dr. Gruenspecht indicated, it ultimately goes down, and if you focus just on the carbon program it increases by no more than 1 percent. The economic dislocations that we have all feared simply do not appear.

I think a lot of that comes to bear on the cost certainty our program provides. It has gotten us out of this “my modeler is smarter than your modeler” debate that causes this dramatic gap in people’s different projections.

But now let me turn a little bit to benefits, because, while the costs have clarified, I think there is a growing disagreement among experts about the benefits and the logic of combining the market program with an incentive program. Predictably, the environmental community has concluded that our $7 a ton initial carbon price is not enough and business and trade associations have suggested that it is too much. I credit Dr. Smith with the I think creative argument, if I understand it, that it is at once not enough and too much, which I think raises the complexity of the debate quite a bit.

But our Commission by and large avoids extremes and I think, like democracy itself, it is best useful to compare this combined approach in the comparison to alternatives. Our alternatives are quite simple. We can either put the entire burden on the private sector—a market signal is a good thing, but I think most agree that Kyoto was too much of a good thing. By placing the entire burden on the private sector, we have unacceptable costs, unacceptable dislocations, and we fail to address the long-term market failures that Dr. Smith addressed through R&D.

But conversely, placing the entire burden on the public sector, which I think is a fair description of the status quo, where we raise tax revenues for big government programs to choose the right technologies, is simply not the way we have learned to solve problems in this country. It provides no incentive for private sector innovation, no incentive to deploy technologies. Even if the taxpayers support the full cost of deployment, if the costs of venting a ton of carbon to the atmosphere there is simply no incentive to bring these technologies forward.

Finally, I think I am personally leery of Apollo metaphors that suggest big government spending, absent any particular strategy to suggest how much money, how it will be spent, ultimately who is going to raise that money. Fundamentally, it is the marketplace and not any of us, no matter how well intentioned or expert, that must ultimately decide how to move these technologies forward.

So in closing, let me just contrast I think the extremes with the benefits of a balanced system. The combination of a modest cost price on carbon and a technology program provides real near-term reductions. Our proposal is anticipated to reduce the growth in annual greenhouse gas emissions by two-thirds over the next decade, allowing us then to move into ultimately a cap and a reduction.

Early market signals avoid locking in bad investments and, contrary to Dr. Smith's expectations, it was the CEO's on our commission, the people who actually make billion dollar long-term investments, who were strongest of the view that a modest market signal now would have dramatic long-term impacts on their ideas and challenges.

It is an equitable approach, Mr. Chairman, because it shares the burdens. Someone is going to have to pay for this technology and it shares the burdens between the public sector and shareholders.

Mr. Chairman, while I think our Commission was a bid prudish in our interest in not exceeding or spending money that we do not have, it provides an opportunity to actually generate revenue so that you can move these technologies forward in a revenue-neutral way.

Finally, Mr. Chairman, it allows us to establish our international leadership. We all agree that we cannot solve this problem absent commensurate and real efforts by China and India. We need to establish our opportunity to work with those countries more aggressively than we can right now. It is clear that we cannot in the United States solve this problem absent participation by those other countries. I think it is equally true that the rest of the world cannot solve this problem absent the leadership of the United States.

Thank you for this opportunity and we offer whatever our Commission can do as you address these difficult issues in the time ahead.

[The prepared statement of Mr. Grumet follows:]

PREPARED STATEMENT OF JASON S. GRUMET, EXECUTIVE DIRECTOR, NATIONAL COMMISSION ON ENERGY POLICY

Good morning, Chairman Domenici and Members of the Committee, and thank you for holding this hearing to explore the benefits and economic impacts of approaches to reduce greenhouse gas emissions. I speak to you today on behalf of the National Commission on Energy Policy, a diverse and bi-partisan group of energy experts that first came together in 2002 and last December issued a comprehensive set of consensus recommendations for future U.S. energy policy.

I would like to begin by commending Chairman Domenici and Senator Bingaman and many others on this Committee for their leadership in winning Senate adoption of a landmark resolution recognizing the importance of the climate problem and, for the first time, putting this body on record in support of the need for mandatory efforts to reduce greenhouse gas emissions. I believe that in years to come, passage of this resolution will come to be seen as a pivotal moment in the evolution of our collective response to the risks posed by climate change.

The resolution marks a turning point, but it also represents a logical next step for the Senate on this issue. When the Senate last expressed its views on climate change—in the Byrd-Hagel resolution of 1997—it set out two basic criteria for future U.S. climate policy that continue to serve as critical guideposts for our discussions today. The first criterion is that any efforts to combat climate change must not compromise the vitality or competitiveness of the U.S. economy. The second criterion is that all nations, and particularly developing nations with rapidly growing emissions, must also act to address this problem. As we heard from the panel of distinguished scientists who testified before this Committee in July, the scientific consensus about climate change has steadily strengthened over the last decade. While a majority of Senators have now agreed that it is time to act, Senators on this Committee have clearly expressed a shared view that the solution to this global problem will not come easily. It was also widely and correctly noted at the previous hearing that mitigating the risks from global warming will require the deployment of an array of clean energy technologies, many of which have not been commercialized or even invented. The challenge before us is to determine the most effective and efficient means of developing and deploying these new technologies while satisfying the criteria articulated in both the Byrd-Hagel and the more recent Bingaman-Domenici resolutions.

Our group, the National Commission on Energy Policy, has developed an approach that we believe can reduce domestic emissions, spur technology development and meet the twin tests of economic responsibility and international equity.

But before outlining key elements of that approach, let me say a few additional words about the Commission itself. The Commission was formed in 2002 by the Hewlett Foundation and several other private, philanthropic foundations. Its ideologically and professionally diverse 16-member board included recognized energy experts from business, government, academia, and the non-profit sector. Our final recommendations, which are described in a report that was released on December 8, 2004, were informed by intense discussions over several years, by dozens of analyses contained in a 2,800 page Technical Appendix, and by extensive outreach to over 200 other groups. Those recommendations, I should stress, deal with a comprehensive set of energy policy issues including (in addition to climate change) our nation's dependence on oil and the need for increased investment in new energy technologies and critical energy infrastructure.

As a group, however, we recognized from the outset that climate change presented one of the central energy challenges of our time and so we devoted considerable energy to developing a detailed set of recommendations for addressing this issue. I would like to begin my remarks by summarizing the Commission's view that volunteerism and tax-payer supported incentives alone do not provide an effective or economically efficient response to this challenge. After explaining our support for mandatory market-based limits to slow, stop and ultimately reverse the growth of greenhouse gas emissions, I will focus on the attributes of a mandatory program that are needed to protect our economy.

The Imperative of Mandatory Action—Our Commission strongly supports the need for continued government efforts to accelerate the development and early deployment of low and non-carbon energy sources. We applaud the Administration's efforts in this regard. However, in a competitive market-economy, where companies are encouraged and in some cases obligated to maximize shareholder value, it is contrary to the rules of free-market competition to expect companies to invest scarce resources absent a profit motive. While there are numerous cases where a combination of good will, good public relations, and positive ulterior motives (like reduced energy bills), create an adequate basis to reduce greenhouse gas emissions, these cases will remain limited if the financial value of reducing a ton of GHG emissions remains zero.

It is somewhat ironic that the European Union is actively implementing market-based regulatory approaches developed here in the Unites States while we pursue a top-down program of government-directed, tax-payer funded research and deployment incentives. Developing and commercializing new technologies will cost money. The question is who is best positioned to secure and effectively spend these resources. While there is certainly a role for public funding and government incentives, the Commission believes. that there must also be a role for those who emit greenhouse gases to share in the costs of developing solutions. As we have learned over the last twenty years, given a rational reason to invest, the private sector is far better than the government in developing technological solutions. The success of the acid rain program demonstrates that the most effective way to engage the ingenuity of the private sector is to place a monetary value on a ton of reduced emissions thus creating a real economic incentive to develop cleaner forms of energy. By imposing a modest market signal to pull private sector technology investment forward in combination with continued tax-payer supported investment to push longer-term solutions, the Commission believes we can significantly reduce GHG emissions without hampering economic growth or prosperity.

Many in the environmental community and some industry analysts have argued that the modest-market signal proposed by the Commission is inadequate, in and of itself, to spur the technology innovation needed to solve the climate problem. The Commission wholeheartedly agrees. While modeling performed by Charles Rivers Associates under contract to the Commission and by the Energy Information Administration demonstrates that a modest carbon price will inspire considerable near-term reductions, both analyses conclude that.proposed market-signal is unlikely by itself to make technologies such as carbon sequestration, a massive deployment of renewable energy generation, or advanced nuclear facilities cost-competitive over the next two decades. This conclusion is precisely why the Commission believes that an effective response to climate change requires both a market signal and significant technology incentives.

This basis of this conclusion is best revealed by examining the alternatives. While providing a strong incentive for technology development, imposing a much higher carbon price on corporations and share-holders would be economically disruptive and politically unacceptable. This approach would strand billions of dollars of existing, long-lived capital stock and cause potentially significant economic dislocations while new technologies were developed and deployed. It also fails to address widely accepted market failures that discourage the investment of private capital in the development of long-term technologies with uncertain market value. Conversely, the placing the entire burden on the public sector is equally unacceptable. By discouraging private investment and innovation, this approach will ultimately prove ineffective, too costly to the Treasury or both. Moreover, absent a market signal, there will be little or no incentive to deploy low carbon technologies even if the tax payer covers the full cost of their development. In sum, relying entirely upon the private or public sectors to advance our national interest in technology advancement, offers a policy prescription that is akin to pushing one-end of a rope.

The elegance of combining a both market signals and public incentives is further supported by the opportunity to auction a small fraction of the emission permits in order support technology innovation without burdening the general tax base. The Commission proposed to double U.S. energy R&D, triple international energy R&D partnerships, and provide significant incentives to accelerate the deployment of coal gasification and sequestration, bio-fuels, renewable generation, domestically produced efficient vehicles and advanced nuclear facilities using the $35 billion in revenue generated by auctioning up to 10% of the emission permits over a decade.

Overview of Commission Proposal—In addition to advocating for the combination of a market-based price signal and technology incentives, the Commission's proposal is explicitly designed to ensure that the proposed market-based emission reduction requirements do not undermine economic growth or competitiveness. Specifically, the Commission recommends that the United States adopt a mandatory, economy-wide, tradable-permits system for reducing greenhouse gas emissions, with a safety valve designed to limit costs. This approach is similar to the successful acid rain program in the United States, but differs in one very critical respect. Rather than proposing a hard cap on emissions, we have proposed an absolute cap program costs.

The aim of the Commission's proposal is to slow growth in U.S. emissions over the 2010-2020 timeframe as a prelude to stopping and eventually reversing current emissions trends in the 2020s and beyond. We also explicitly designed our approach to recognize the importance of participation by major trading partners like China and India. Our program includes a regular 5-year review of progress which is intended to assess both the performance of the U.S. program *and* progress by other countries. If major U.S. trading partners and competitors (including China, India, Mexico, and Brazil) fail to implement comparable emission control programs, further U.S. efforts—including the gradual increase in stringency built into our program—could be suspended or adjusted. Conversely, the U.S. program could be strengthened if international progress, technology advances, or scientific developments warrant.

International participation and other issues will be the subject of future hearings, so I want to return now to the main focus of this panel: economic impacts.

Two key policy choices: 1) a modest reduction target; 2) the cost-cap or "safety-valve" enable the Commission to propose a mandatory, economy-wide GHG reduction program that according to EIA does not "materially affect," the U.S. economy. I will describe each of these design features in turn.

Modest Reduction Target—The Commission believes that if we begin now, there is time to gradually phase-in GHG reductions across the economy. Like the Administration, we believe that reducing the GHG intensity of the economy is an effective means of slowing, stopping and ultimately reducing U.S. GHG emissions. Over the first decade of the program, we propose to set an economy-wide emission limit based upon a 2.4% decrease in GHG emission intensity. If achieved, this target would slow annual emissions growth by roughly ⅔ from business as usual allowing actual emissions to increase by 0.5% per year instead of by the currently projected 1.5% annual increase in total emissions. Absent Congressional intervention to adjust the target, the intensity decline would increase to 2.8% after a decade effectively stopping emissions growth. Many have argued that this reduction pathway is too slow and criticize the Commission plan for explicitly allowing emissions to increase for a decade after implementation. We acknowledge this critique, but believe that a modest and low-cost reduction pathway is critical to achieving the near-term consensus needed for timely action. The Commission believes that it is critical for the United States to move forward now to implement a robust regulatory architecture that can adjust over time as our understanding of climate impacts and the costs of solutions matures.

Cost-Certainty (the "Safety-Valve")—Under a traditional cap and trade program the reduction target is fixed in statute or regulation while the costs are "best guesses" of what will be necessary to achieve the fixed targets. While our experience in the acid rain program suggests that projected costs are more likely to be exaggerated than understated, there remains a real possibility that costs for meeting any target will be higher than expected or desired. Under the safety-valve, regulated entities are allowed to buy additional permits from the government at a pre-determined price. This feature of the Commission's proposal ensures that program compliance costs will not exceed estimates. If technology fails to progress at the projected rate, the program will reduce less emissions than desired but compliance costs will not increase.

EIA's analysis and the work of Charles River and others reveal that expectations of technological progress are by far the most significant assumptions affecting the costs of achieving a particular emissions target Under EIA's base-case average technology assumptions achieving the Commissions modest 2.4% annual intensity reduction will begin to cost more than the safety-valve price beginning in 2015 causing firms to avail themselves of safety-valve permits. However, when EIA projects costs using more optimistic assumptions about technology progress that seek to capture the Commission's "recycling" of auction revenue back into technology incentives, the target is met throughout the first decade with the safety-valve never being triggered at all. Under the more optimistic technology assumptions, a $7/ton incentive results in nearly double the reductions, but the overall cost of the program is the same.

The Commission's decision to place a priority on cost-certainty over emissions certainty reflects our appreciation of strongly held and fundamentally irresolvable disagreements about technological progress and the ultimate costs of emission reductions. Rather than spending several more years paralyzed by differing climate change modeling assumptions, the safety-valve allows us to begin, albeit cautiously, to reduce U.S. greenhouse gas emissions while protecting our economy, affording time for key industries to adjust and maintaining America's global competitiveness.

The safety valve also gives businesses the planning certainty they need to make wise long-run investments that will minimize the costs of achieving greenhouse gas emissions reductions over time. We chose an initial safety valve level of $7 per metric ton of carbon dioxide equivalent because analyses suggest that it roughly reflects the mid-point in the scientific literature of the expected harm that can presently be attributed to a ton of GHG emissions given current scientific understanding. Equally if not more important, the $7 figure is low enough to ensure that valuable, long-lived energy assets won't be prematurely retired, yet also high enough to send a meaningful market signal for future investment in clean, low-carbon energy alternatives. In our proposal, the safety valve price increases gradually over time, at a nominal rate of 5 percent per year, to generate a steadily stronger market signal for reducing emissions.

Overall Economic Impacts—To assure ourselves that we had successfully addressed potential economic concerns, we subjected our proposal to detailed economic analysis. The analysis indicated that the impacts of the program on businesses and households would be modest. Our own modeling results were subsequently supported by an independent analysis of our proposal by the Department of Energy's Energy Information Administration (EIA).

EIA's analysis indicates that the impacts of the program on businesses and households are likely to be modest. Projected annual GDP growth would decline by less than .02% against a baseline average growth or 3.1%. This impact equate to an average annual cost of $78 per household between program inception and 2025. Assessed cumulatively between 2005 and 2025, overall, predicted GDP growth would change from 80.8 percent to 80.6 percent, or a difference of 0.2 percent. In the EIA's own words: "the overall growth rate of the economy between 2003 and 2025, in terms of both real GDP and potential GDP, is not materially altered." Put another way, the nation would be as wealthy on January 15, 2025 with the program in place, as it would have been on January 1, 2025 under business as usual. At the relatively minor cost of slowing economic growth by two weeks twenty years hence, we can make a significant start to address global climate change.

Because the models predict that a large share of reductions in the early years of the program would come from industrial greenhouse gases such as HFCs, PFCs, and SF6, total energy consumption would be expected to decline by only 1 percent below forecast levels for 2020, while still growing 14 percent in absolute terms over the first decade of program implementation (i.e., 2010-2020). Also noteworthy, natural gas demand is barely affected by the Commission's climate proposal increasing by less than 1% over business as usual. When additional proposals to increase energy efficiency and support coal gasification are modeled, total natural gas demand actually declines against business as usual projections. Finally, while coal use grows more slowly than under BAU, significant growth in coal is projected by both the Commission and EIA's analysis even when excluding new markets that will be created by IGCC.

Of course, a very small fraction of a very large economy can still look like a lot of money if taken out of context. You will undoubtedly hear from critics that our proposal will cost $313 billion in lost GDP between 2005 and 2025. What the critics are less likely to mention is that this is just a tiny fraction of the $323 trillion of cumulative growth in GDP the economy is expected to generate over the same time period. Similarly, those who oppose any action on climate change are likely to point to EIA's estimate of 140,000 lost jobs by 2020 as a result of the tradable permits program. Again, this number needs to be viewed in context. EIA's estimate of job losses comes to just 0.4 percent of the 36 million new jobs that the economy is expected to create between 2005 and 2025.

At Chairman Inhofe's request, EIA also recently examined the impacts of the program assuming higher natural gas prices and higher costs for reducing emissions of non-CO_2 greenhouse gas emissions. EIA found that the costs of the Commission's proposal would actually be less if natural gas prices turned out to be higher than projected. Higher natural gas prices under business-as-usual assumptions would tend to lower total demand for energy, thus making it somewhat easier to meet the Commission's proposed emission target. While more pessimistic assumptions regarding the costs of controlling non-CO_2 greenhouse gas emissions would result in lower total reductions of greenhouse gas emissions, they would not materially affect program costs. This recent analysis makes clear the value of the safety-valve both as a substantive protection in case 2005 economic assumptions are not borne out over time and as a political device to set aside some of the more contentious and unknowable "what if" arguments that have undermined our ability to forge a consensus for mandatory actions to reduce GHG emissions.

The trade-off for low cost is a program that also achieves relatively modest emission reduction benefits, at least in its early stages. We believe that a flexible, gradual, market-based approach that provides cost certainty is appropriate at a time when uncertainties remain about the pace of actual warming and about the speed with which we can develop and commercialize lower-carbon alternatives. While this program will necessarily need to evolve as other nations join in the reduction effort and as our understanding of the climate induced impacts continues to improve. We believe that it is the right approach to get us started.

In fact, the importance of getting started is exactly what I hope you will not lose sight of as the inevitable debate about numbers and dollars and tons and jobs unfolds in the months to come. A war of numbers too easily leads to paralysis. And right now it matters less which numbers you choose than that you recognize the essential principle at the core of our proposal: Strictly voluntary, seemingly costless approaches will not enable the marketplace to attach a known value to carbon reductions. Only when reductions have real value—however small—can companies justify long-term investments in new, low-carbon energy alternatives and only then will we unleash the ingenuity and innovation of the private sector in addressing the climate change problem and in developing the clean technologies that will be in global demand for decades to come.

Finally, the Commission firmly recognizes that climate change is a global problem requiring an effective and equitable global solution. The United States can not meaningfully mitigate the risks of climate change absent commensurate efforts by the rest of the world. Similarly, the rest of the world can not solve the climate problem absent leadership from the United States. The Commission believes that undertaking mandatory domestic reduction efforts here at home is a condition precedent to achieving a truly global solution. This recognition that actions in the developing world will inevitably follow those of the United States provides further impetus to take action now so that we can work more effectively to encourage similar actions overseas.

Thank you for this opportunity to testify. I speak on behalf of the entire Commission in offering whatever further support and information we can provide to assist your deliberations in the months to come.

SUMMARY OF KEY FEATURES OF THE NATIONAL COMMISSION ON ENERGY POLICY'S PROPOSAL FOR REDUCING GREENHOUSE GAS EMISSIONS

- *Mandatory, economy-wide, tradable permits system* would go into effect in 2010. This would allow U.S. companies adequate lead time to plan and make needed adjustments or investments. The program would cover carbon dioxide (CO_2) and other major greenhouse gases (including methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride).
- *Environmental target based on annual reductions in emissions intensity*, where intensity is measured in tons of CO_2-equivalent emissions per dollar of GDP. Between 2010 and 2019 the Commission recommends a target emissions intensity decline of 2.4 percent per year. Based on current GDP forecasts, achieving this target would reduce projected emissions growth from a business-as-usual rate of 1.5 percent per year to 0.5 percent per year. Starting in 2020 and subject to the Congressional review described below, the Commission proposes raising the target intensity decline to 2.8 percent per year (the "stop phase" in the figure).
- *Cost cap* is achieved by making additional permits (beyond the quantity of permits established through the target intensity decline described above) available for purchase from the government at a pre-determined price. The Commission proposes an initial cost cap or "safety valve" permit price of $7 per metric ton of CO_2-equivalent. This price would increase by 5 percent per year in nominal terms.
- *Permit allocation* for a given year would be calculated well in advance based on available GDP forecasts. For the first three years of program implementation, the Commission recommends that 95 percent of initial permits be issued at no cost to emitting sources. The remaining 5 percent would be auctioned. Starting in 2013 and every year thereafter, an additional 0.5 percent of the target allocation would be auctioned, up to a limit of 10 percent of the total permit pool.
- *Congressional review in 2015 and every five years thereafter* to assess the U.S. program and evaluate progress by other countries. If major U.S. trading partners and competitors (including China, India, Mexico, and Brazil) fail to implement comparable emission control programs further U.S. efforts (including continued escalation of the safety valve price and permit auction, as well as more aggressive intensity reduction target in 2020) could be suspended. Conversely, the U.S. program could be strengthened if international progress, technology advances, or scientific developments warrant.

The CHAIRMAN. Thank you.

Dr. Morgenstern.

STATEMENT OF RICHARD D. MORGENSTERN, PH.D., ECONOMIST AND SENIOR FELLOW, RESOURCES FOR THE FUTURE

Dr. MORGENSTERN. Thank you, Mr. Chairman. Mr. Chairman, Senator Bingaman, members of the committee, I appreciate the opportunity to appear here today. I am an economist and senior fellow at Resources for the Future, a 53-year-old nonpartisan think tank based here in Washington. The views I present are strictly my own.

I begin by observing what many press reports have failed to note, that proposals such as those advanced by the NCEP differ dramatically from the Kyoto Protocol. Whereas Kyoto sought significant near-term reductions, NCEP is designed not to avert climate change over the next 20 years. Rather, its principal aim is to develop and deploy new technologies to address the problem in the decades ahead.

Recent EIA analyses, which we have already heard from Dr. Gruenspecht on, clarify the differences. I have a table in my testimony that demonstrates this clearly, but looking at several analyses conducted by EIA over the past several years, the differences are striking between NCEP and Kyoto. What you find is that the reductions are only about one-fifth as much as those proposed under Kyoto in NCEP, allowance prices in 2020 are about eight dollars a ton of CO_2, and although there is a small decline compared to the forecast level, coal use actually increases 14 percent over the current levels. The overall economic impacts measured in terms of potential GDP are about one-eighteenth as much as the Kyoto Protocol.

The NCEP approach relies on market-based policies, in this case a cap-and-trade mechanism, with a safety valve or price cap, combined with a set of direct subsidies to new technologies. The revenues are derived from a sale of a small portion of the allowances. Thus the NCEP proposal is revenue neutral.

Market-based mechanisms of this sort have two distinct effects. On the one hand, they create incentives to reduce emissions in the near term, thus mitigating environmental damages associated with those emissions. Second, they alter incentives for the private sector to develop and adopt new technologies. In fact, few would disagree that it is the private sector, not the Government, which has driven innovation and growth in our society. According to the National Science Foundation, for example, industry funded about two-thirds of the research and development in this country in 2003.

While anecdotal evidence on the private sector contribution is extensive, I would call your attention to a recently published scholarly paper by David Popp. It documents that following the passage of the Clean Air Act in 1990, which for the first time put an incentive on the development of technologies which would reduce emissions beyond the targeted level, that the level of patent activity for these particular types of innovations which increased the effectiveness, the environmental effectiveness of these technologies, increased. Heretofore the emphasis in new patents had been focused principally on only cost-reducing technologies, but it was this emphasis on environmentally friendly reductions which was induced as a result of the Clean Air Act.

At the same time, there is an important role for government clearly in encouraging the development of new technologies, based largely on the spillovers and externalities associated with innovations. The existence of these spillovers reduces the private incentives to pursue innovation as others will mimic these initial innovations without compensating or fully compensating the inventors. Patents offer some protection, but that is limited. Learning by doing creates additional benefits for society from the early adoption and diffusion of these technologies.

While the rationale for government support of research and development and demonstration is quite strong, such programs cannot do the job completely by themselves. For example, government-funded technology programs may succeed in bringing down the cost of promising technologies, like IGCC, so that they will eventually overtake conventional pulverized coal technologies.

That said, how can technology programs ever make capture and sequestration cheap enough so that firms will voluntarily undertake such efforts? To accomplish sequestration, some form of mandatory government policy is going to be required. The real choice is between a command and control approach and a market-based approach. NCEP has wisely chosen a market-based approach to encourage this near-term mitigation.

Now, those who oppose a mandatory program fail to recognize several points. First, the signal that it sends to firms and households, especially in their investment decisions for long-lived equipment, like power plants, homes, and many appliances. Second, the value of cheap near-term reductions in buying time for further R&D on these new technologies. Third, the opportunity to encourage a broad set of technologies, not just the winners picked by the Government program.

Virtually all economists recognize the rationale for some form of mandatory program. Arguably, there is a disagreement about the extent of the disincentive for carbon emissions that should be imposed in the near term. The NCEP recommendation of $7 a ton of CO_2 is quite consistent with the estimates found in the economics literature on this point.

Let me now turn to a further discussion of the safety valve. As has been noted by others, it is in effect a type of insurance designed to protect the economy against unexpected price increases caused by weather, stronger than predicted economic growth, technology failures, or other factors. Despite the success of the cap-and-trade approach without the safety valve in the acid rain program, problems have arisen in some other arenas.

For example, during the California energy crisis the price of NO_X permits rose to about $80,000 per ton. More recently, in the early phase of the European Union trading system prices have moved around fairly dramatically. Canada, our neighbor to the north, has included a safety valve in its recent proposals on climate change.

Now, differences among forecasters have plagued previous policy proposals. Back in 1997, the Council of Economic Advisers forecast prices below the equivalent of $8 per ton of CO_2, compared to EIA's estimate of $43 per ton of CO_2. With a safety valve, emissions estimates may vary, but costs cannot rise above the established price.

Some in opposing the safety valve try to label it as a disguised tax. In this regard I would make two points. First, if the price cap is not reached then it is strictly a cap-and-trade mechanism, just like the acid rain program. However, even if the price cap is reached, only a very small portion of the revenues flow to the government, in this case to fund the R&D. The bulk of the revenues flow directly back to the private sector. Since a tax is principally defined in terms of the revenues it generates and since only a small portion of the revenues ever end up in the hands of government, it clearly is inaccurate in my judgment to describe it as a tax.

In conclusion, Mr. Chairman, we have come a long way since the early discussions on the Kyoto Protocol. We are no longer talking about steep emissions reductions with concurrent risks to the economy. Rather, the debate has now shifted to the appropriate mechanism for motivating both the public and private sectors to pursue technology innovation over the long term and capturing the low-hanging fruit of cheap emissions reductions in the short run, all the while protecting us from unwarranted economic impacts.

That completes my initial remarks and I would be pleased to answer any questions. Thank you.

[The prepared statement of Dr. Morgenstern follows:]

PREPARED STATEMENT OF RICHARD D. MORGENSTERN, PH.D., ECONOMIST AND SENIOR FELLOW, RESOURCES FOR THE FUTURE

Mr. Chairman, I am pleased to appear before this committee to comment on the recently adopted Senate resolution calling for a ". . . national program of mandatory market-based limits and incentives on greenhouse gases that (1) will not significantly harm the United States economy; and (2) will encourage comparable action by other nations that are major trading partners and key contributors to global emissions."

To set the context, I will briefly discuss a number of policy developments since the late 1990s when the Kyoto Protocol was being negotiated. Then, I will turn to some design issues relevant to the implementation of the new Senate Resolution, including the mechanisms that will encourage the development and adoption of new technologies, and the use of a safety valve or price cap as an integral part of a cap-and-trade system. Finally, I will comment on possible means of encouraging comparable mitigation actions by other large emitters.

I speak as an economist who has been involved with the issue of climate change for almost two decades. Previously a tenured college professor, I have also had the privilege of serving in senior policy positions under prior Republican and Democratic administrations. Currently, I am a senior fellow at Resources for the Future (RFF), a 53-year-old research institution, headquartered here in Washington, D.C., that specializes in energy, environmental, and natural resource issues. RFF is both independent and nonpartisan, and shares the results of its economic and policy analyses with members of both parties, as well as with environmental and business advocates, academics, members of the press, and interested citizens. RFF encourages scholars to express their individual opinions, which may differ from those of other RFF scholars, officers, and directors. I emphasize that the views I present today are mine alone.

Let me begin by observing what many recent press reports have failed to note: recent policy proposals, such as those advanced by the National Commission on Energy Policy (NCEP), differ dramatically from the Kyoto Protocol. While the details of Kyoto are well known to members of this committee, the NCEP proposal is novel in a number of respects, as it combines federal support for innovative technologies with a program to reduce greenhouse gas emissions that involves a cap on costs. Overall, the NCEP program would have a minimal impact on the U.S. economy and is revenue neutral with respect to the federal budget. Whereas the Kyoto Protocol involves fairly steep short-term reductions and, correspondingly, potentially high costs, the NCEP proposal calls for relatively modest initial emissions reductions which are, in fact, quite similar to the voluntary intensity reductions proposed by the Bush administration. Because of the more modest start, combined with the safety valve, the costs of the NCEP proposal are much lower.

To see this point more clearly, consider the results of three separate analyses by the independent Energy Information Administration (ETA) of the costs of alternative climate proposals conducted over the past several years. Relying on its standard National Energy Modeling System, ETA compared the effects of implementing the Kyoto Protocol, The Climate Stewardship Act introduced by Senators McCain and Lieberman (S. 139), and the NCEP proposal. Although the EIA studies were conducted in different years, and involve slightly different baselines, the results are quite illuminating (see the accompanying table).

EIA's ANALYSIS OF THE KYOTO PROTOCOL, S. 139, AND ENERGY COMMISSION PROPOSALS: 2020

	NCEP	S. 139	Kyoto (+9%)
GHG emissions (% domestic reduction)	4.5	17.8	23.9
GHG emissions (tons CO_2 reduced)	404	1346	1690
Allowance price ($2003 per ton CO_2)	8	35	43
Coal use (% change from forecast)	−5.7	−37.4	−72.1
Coal use (% change from 2003)	14.5	−23.2	−68.9
Natural gas use (% change from forecast)	10.6	4.6	10.3
Electricity price (% change from forecast)	3.4	19.4	44.6
Potential GDP (% loss)	0.02	0.13	0.36
Real GDP (% loss)	0.09	0.22	0.64

SOURCES.

NCEP: GHG emissions and allowance price is from EIA analysis, Table 118 (May 2005). All other data is from Table 1, "AEO 2005 Reference Case" and "Greenhouse Gas Policy." (EIA, April 2005). This is available at *www.eia.doe.gov/oiaf/servicerpt/bingaman/index.html.*

McCain Lieberman (S. 139): From Analysis of Senate Amendment 2028, the Climate Stewardship Act of 2003. Emissions data and allowance price is from Table B20. GDP is from Table B21. All other data is from Table B1. (ETA, May 2004). This is available at *www.eia.doe.gov/oiaf/servicerpt/ml/pdf/sroiaf (2003)02.pdf.*

Kyoto Protocol: Impacts of the Kyoto Protocol on U.S. Energy Markets and Economic Activity. Emissions data is from Table B19. Allowance price and GDP is from Table ES-2. All other data is from Table B1. (EIA, October 1998). This is available at *www.eia.doe.gov/oiaf/kyoto/pdf/sroiaf9803.pdf.*

For the Kyoto Protocol, EIA forecast greenhouse gas reductions of 23.9 percent in 2020. Under Kyoto, allowance prices were predicted to reach $43 per ton of carbon dioxide, while coal use was expected to decline by 68.9 percent below 2003 levels. Real GDP was forecasted to decline by 0.36 percent. In analyzing the NCEP proposal, EIA foresaw smaller emissions reductions and, most importantly, quite different economic impacts. Allowance prices were effectively capped at $7 per ton of carbon dioxide; coal use was forecast to increase by 14.5 percent above 2003 levels by 2020, and real GDP losses were considerably smaller (0.09 percent). EIA noted that this policy would not "materially" affect average economic growth rates for the 2003 to 2025 period (p. xi). For McCain Lieberman, EIA forecast impacts that would fall between Kyoto and NCEP, although they were considerably closer to Kyoto in terms of both emissions reductions and costs.

The principal reason that NCEP's approach is so much less costly than Kyoto or S. 139 is that it is not designed to avert climate change over the next 20 years. Rather, the focus is on developing and deploying technologies needed to address the problem in the decades beyond. NCEP does this primarily in two ways: 1) by directly subsidizing a wide range of new technologies including coal, nuclear, fuel-efficient vehicles, biofuels and others; and 2) by encouraging private-sector research and development through incentives for the deployment of cost-effective carbon saving technologies of all types. NCEP's cap-and-trade system has the added benefit of generating a revenue stream to fund the technology subsidies.

It is widely recognized that major progress on climate change will not be possible without new technologies. It is also widely recognized that government has an important role to play in spurring the development and diffusion of these technologies. Without some kind of additional incentives, the private sector typically will under-invest in research, development, and demonstration because innovators cannot reap the full benefits to society of their advances. The existence of these "spillovers" reduces private incentive to pursue innovation, as others will mimic the innovation without compensating the inventors. While patents and similar means are used to protect investments in innovation, that protection is limited. A successful innovator typically captures substantial rewards, but those gains are sometimes only a fraction of the total benefits to society arising from the innovation. This rationale underlies government support of research, development, and demonstration programs, including the National Science Foundation, public universities, and others.

Environmental and knowledge externalities have long been at the center of debates about technology policy. More recently, we have come to understand some additional market failures that may operate in the adoption and diffusion of new technologies. For a variety of reasons, the cost or value of a new technology to one user may depend on how many other users have adopted the technology. Generally speaking, users will be better off the more others use that same technology, as this increases what is known as "learning by doing" and "network" externalities. Typically, it takes time for potential users to learn of a new technology, try it, adapt it to their particular circumstances, and become convinced of its superiority. Consequently, the early adopter of a new technology creates a positive benefit for others by generating information about the existence, characteristics, and likely success of the new technology.

The argument for public support is even stronger in the case of climate change technologies, where not only do inventors fail to capture all the gains from their investments but the gains themselves are not fully translated to the firms' bottom line because there is no market value associated with emissions reductions. Further, the prospect of future value—which is driven by policy outcomes—is uncertain.

Absent government incentives, corporate concern for the environment may overcome some hurdles. Working against this kind of "corporate altruism," however, is the need to compete in the marketplace. A company that puts meaningful effort into reducing greenhouse gas emissions, rather than reducing costs, may eventually lose out to one that only seeks to reduce costs.

It is exactly this need to align public and private interests that underlies the argument for an emissions trading program, or similar mechanism, alongside technology development and demonstration programs. While the government seeks technologies to cut carbon emissions, the private sector seeks technologies to cut costs. Market-based policies that put a value on emissions reductions encourage firms to conserve energy, reduce emissions from existing technologies, and adopt new low-carbon or no-carbon technologies. In contrast, policies that only focus on technology adoption fail to take advantage of reductions that could come from existing technologies and conservation.

Market-based policies to reduce emissions have two distinct effects: they reduce emissions in the near term and they alter the incentives that firms have for developing and adopting new technologies for the future. Few would disagree that it is the private sector, not the government, which has driven innovation and growth in modern economies. Industry, according to data from the National Science Foundation, funded 63 percent and performed 68 percent of all research and development in 2003 (the latest year for which data is available).[1] Even as the government tries to encourage greenhouse gas-*reducing* technologies, private efforts to improve greenhouse gas-increasing technologies will likely continue unless firms see some kind of value associated with emissions reductions.

Technology programs alone may succeed in bringing down the cost of integrated gasification and combined cycle (IGCC) coal plants so that they eventually overtake conventional pulverized coal. That said, how can technology programs ever make capture and sequestration cheap enough so that firms will voluntarily capture and sequester emissions? The real choice is whether capture and sequestration will eventually be required under a command-and-control style regulation, or whether a market-based system will be used to flexibly encourage adoption of the cheapest option. There is growing evidence on the performance of these alternative approaches, including a volume I recently co-edited which compares the U.S. and European records of both command-and-control and market-based mechanisms.[2] Overall, the analysis finds that market-based programs are considerably cheaper than command-and-control alternatives. For example, the U.S. sulfur dioxide program achieved savings of over 40 percent compared to the command-and-control alternatives. Additionally, market-based programs have the advantage of encouraging innovation in a direction that minimizes costs and reduces emissions.

Another point sometimes overlooked is the opportunity for relatively inexpensive emissions reductions right now. Emissions reductions using more conventional technologies may not provide a complete solution to the climate problem, but by delaying the accumulation of greenhouse gases in the atmosphere, they provide additional time to develop long-term solutions. Even if a major technology breakthrough is needed to reach climate stabilization goals, there are many small-and medium-sized innovations—the type typically associated with learning by doing—that can yield significant benefits. Sending a signal about the value of emissions reductions provides the right information to the private sector about the importance of undertaking those activities.

Consistent with this logic, the NCEP proposal tries to link the technology development and the mitigation sides of the problem into a coherent policy framework. By coupling technology incentives with an emissions trading program they provide sig-

[1] *www.nsf.gov/sbe/srs/infbrief/nsf04307/start.htm.*

[2] Harrington, Winston, Richard Morgenstern and Thomas Sterner. 2004. *Choosing Environmental Policy: Comparing Instruments and Outcomes in the United States and Europe* Washington D.C.: RFF Press

nificant incentives—along with the necessary funding—to develop new technologies that are essential to the long-term success of any effort to reduce greenhouse gases.

As a final point on the link between research and development, and mitigation, I will mention one particular line of thought in circulation these days that is somewhat at odds with the ideas laid out here. Because climate change is such a long-term problem, the thinking goes, it is not appropriate to encourage emissions reductions now—the policy focus should, instead, be entirely oriented to technology development. Although there are many complex issues here, the single point I would make is that even this view supports near-term emissions reductions as long as the cost is no higher than the expected value of future mitigation benefits. While one can debate the true magnitude of these benefits, the economics literature on this issue would certainly support the $7 per ton of carbon dioxide proposed by NCEP.

I now turn my focus to a discussion of the use of a safety valve or price cap to avoid unpleasant cost surprises. In the context of a mandatory cap-and-trade system, a safety valve would specify a maximum market price at which the government stands ready to sell additional emissions allowances in order to prevent excessive prices.

At the outset, one must ask a basic question: given the success of cap-and-trade programs without a safety valve, such as the one for sulfur dioxide, what is the basis for including a safety valve to control carbon dioxide and other greenhouse gases? The answer is simple and straightforward: carbon controls are potentially more costly to the economy than these other programs and, most importantly, there is greater uncertainty about the true costs. Unforeseen events such as a warm summer or cold winter, a spurt in economic growth, or a technological failure of some sort, may drive up control costs dramatically. One needs only point to the unforeseen events in California's RECLAIM program that propelled the prices of permits for nitrogen oxides above $80,000 per ton, or the similar, albeit less costly, problems that arose in comparable programs on the East Coast. Because of these concerns a number of nations are considering safety valves. For example, Canada recently announced it would incorporate such a mechanism in its domestic program.

As Harvard economist Martin Weitzman pointed out three decades ago, when higher control costs are of concern but the potential environmental damages are not particularly sensitive to short-term emissions fluctuations, it is unnecessary to impose strict quantity-based controls. Although the experience with sulfur dioxide trading suggests that the actual costs may be lower than expected, recent Congressional debates indicate a clear concern that mandatory carbon mitigation policies may become quite costly—even those involving modest targets. Part of the cost uncertainty arises from uncertainty about the level of future baseline emissions that would occur even in the absence of new policies. There are also uncertainties about the cost of reducing emissions below baseline, and about the overall efficiency of the emissions trading system.

One way to address this issue is by using a safety valve that fixes binding emissions targets as long as costs remain reasonable and allows the target to rise if costs are unexpectedly high. In practical terms, the safety valve would involve an initial allocation of permits followed by the subsequent sale of additional permits that would become available at a fixed trigger price. Several of my RFF colleagues and I first proposed applying this mechanism to the control of carbon dioxide back in 1997.[3] Recently, NCEP has embraced the idea as part of a broader package that involves incentives for technology development, as described previously.

In daily life, most individuals like to avoid unpleasant surprises (hence the popularity of insurance). It is possible to use certain policy options to avoid unpleasant surprises in the broader economy as well. Just as the Federal Reserve protects against wide swings in bond and currency prices, the incorporation of a safety valve in a greenhouse gas mitigation policy would prevent sharp increases in energy prices. The ideal climate policy is one that sets an upper limit on mitigation expenditures. Most consumers are interested in reducing their out-of-pocket expenditures for energy as well as other goods and services, and most businesses are interested in maintaining a stable environment for purposes of planning and investment. The risk of unexpectedly high compliance costs under a strict permit system would threaten that stability.

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[3] Kopp, Raymond J., Richard D. Morgenstern, and William Pizer 1997."Something for Everyone: A Climate Policy that Both Environmentalists and Industry Can Live With," *Weathervane*, September 29, available at *www.weathervane.rff.org/features/feature015.html*. Kopp, Raymond J., Richard D. Morgenstern, and William Pizer. 2000. "Limiting Cost, Assuring Effort, and Encouraging Ratification: Compliance under the Kyoto Protocol," *Weathervane*, June 26, available at *www.weathervane.rff.org/features/parisconf0721/KMP-RFF-CIRED.pdf.*

The safety valve approach guarantees that emissions will not exceed the target as long as the price of the tradable permits does not rise above the trigger price. It differs in a few important respects from a well-known provision in the 1990 Clean Air Act Amendments that establishes a $2,000 per ton penalty (1990$) for violations of the stipulated sulfur dioxide emissions standards. Since the Clean Air Act penalty is far above the expected marginal control cost, it has a very low probability of being invoked. The notion of a safety valve reflects the society's willingness to pay for carbon mitigation. It is not intended strictly as a punitive measure. For those who believe that the costs of reducing greenhouse gas emissions are relatively low, permit prices would never reach the trigger level and emissions would remain capped.

One thing that has plagued policy proposals in the past is that different analysts using different models can produce quite disparate results. For example, in analyzing the Kyoto Protocol, President Clinton's Council of Economic Advisers forecasted allowance prices below $7 per ton of carbon dioxide as compared to EIA's $43 estimate. Interestingly, with the safety valve the emissions estimates may vary among models but the costs cannot rise above the price cap. Observe that the EIA estimates of the NCEP proposal, which contains a safety valve, are extremely close to those of the respected consulting firm, Charles River Associates, which conducted that macro-economic analysis for NCEP. Similarly, recent EIA sensitivity analyses of the NCEP proposal reveal that compliance costs are virtually invariant with respect to a wide range of assumptions about natural gas supplies, the availability of non-carbon offsets, and other factors.

A final point about safety valves concerns the claim by some that such a mechanism is unnecessary as long as banking and offsets are allowed. Citing the successful sulfur dioxide trading system, unexpected events of the type that doomed the RECLAIM program in California are dismissed as the product of a flawed design—namely, the absence of provision for emissions banking and offsets—rather than as an inherent problem of applying a fixed quantity trading system to control emissions. The alternative view, espoused by at least two former chairmen of the President's Council of Economic Advisors, is that banking or offset systems cannot reasonably adapt to unexpected events such as higher energy demand or inadequate technology as effectively as a safety valve. According to this view, offsets can reduce the expected cost of a particular goal, but they cannot address concerns about unexpected events. In fact, if the system becomes dependent on such offsets, their inclusion can actually increase uncertainty about program costs if the availability and cost of the offsets themselves is not certain. In regard to the banking or borrowing of emissions, the two Council chairmen note that ". . . [The] . . . features that . . . provide additional allowances when shortages arise...are helpful, but only to the extent they can ameliorate sizeable, immediate and persistent adverse events."[4] That is, offsets or banking systems may reduce the problem, but they may not be sufficient to address all the uncertainties arising from unexpected spurts in economic growth, weather variations, or other events.

Finally, I will briefly comment on the challenges of bringing developing countries into an emissions limiting agreement. While this is clearly a critical need for long-term success of any effort to address climate change, so far, no proposal has made much headway in this area. Developing nations are certainly not lining up behind the idea of binding emissions limits as laid out in the Kyoto Protocol. The president's proposed use of intensity targets, which takes into account economic growth when measuring environmental performance, is more attractive to some developing nations than fixed emissions levels. However, there is no serious indication that developing nations are prepared to adopt this approach either. Senators McCain and Lieberman's Climate Stewardship Act incorporates some limited incentives for developing nations by allowing up to 15 percent of the total emissions to come from offsets, including offsets from abroad. Recent proposals by Senator Bingaman incorporate a similar mechanism, albeit at a lower (three percent) level. How well such international offsets would compete against domestic agricultural and forestry projects, or against domestic non-carbon dioxide sources is an open question. Nonetheless, this approach clearly has some appeal.

The recent Senate resolution on climate change represents an important step forward in redefining the initial terms of developing country participation in greenhouse gas mitigation by opening the door to potential linkages between climate change and other issues of international concern. The original Byrd-Hagel language requiring "new specific scheduled commitments to limit or reduce greenhouse gas emissions" by developing countries has been replaced by the stipulation that U.S. policies "encourage comparable action by other nations that are major trading part-

[4] Hubbard, R. Glenn and Joseph E. Stiglitz. 2003. "Letter to Honorable John McCain and Honorable Joseph Lieberman," June 12.

ners and key contributors to global emissions." This new language lowers the bar somewhat for developing countries and creates a more realistic expectation for participation by these countries. At the same time, it properly focuses attention on major trading partners with large emissions.

Consistent with this new Senate language, a proposal advanced by Senator Bingaman calls for periodic Congressional review of the new U.S. mandatory program. Under this mechanism Congress would make a determination every five years to accelerate, decelerate, or leave unchanged the key program parameters including the emissions target and the safety valve price. In making this determination, Congress would review a wide range of factors, including recent technological advances. Of particular interest would be the mitigation actions of other nations, both developed and developing, to reduce emissions. Further, if the United States or other developed nations had established a program to support clean energy projects in a poor nation, that too would become part of the review. If one believes, as I do, that the key to international cooperation on climate change is linkage on a broad range of issues, including global trade, development aid, and technology transfer, then such a procedure would potentially provide Congress an opportunity to influence the actions of both developing and developed nations as climate policies evolve over the next few years, all the while avoiding, in EIN's words, "material" impacts on the U.S. economy.

In sum, Mr. Chairman, we have come a long way since the early discussions on the Kyoto Protocol. We are no longer talking about steep near-term emissions reductions with the concurrent dangers for the U.S. economy. Rather, the debate has now shifted to motivating both the public and private sectors to pursue technology innovation over the long term and capturing the low-hanging fruit of cheap emissions reductions in the near term, all the while protecting the economy from unwarranted burdens. Such an approach has great potential to encourage the development and adoption of new technologies that can put the United States and other nations on a long-term path to address the climate change issue.

I thank you for the opportunity to appear before this committee and I would be pleased to answer any questions.

The CHAIRMAN. Thank you very much.

I think I am going to do what I have usually done and hold mine for another time. Senator Bingaman, you can start and I will ask my questions later.

Senator BINGAMAN. Well, thank you very much. Thank you, all of you, for your testimony.

Let me just try to take the framework that Dr. Morgenstern has laid out and ask Mr. Grumet if he thinks it is an accurate description of what is involved here. First, he talks about the contrast between a command and control approach to dealing with greenhouse gas emissions versus a market-based approach, and characterizes this national commission proposal as a market-based approach which tries to send a modest signal to the market that will cause the development and promotion of new technologies. He says that is the primary objective, as I understand what he just testified to, that is the primary objective the commission is trying to achieve with its recommendations.

Do you agree that is the primary objective?

Mr. GRUMET. I think Dr. Morgenstern's characterization is fundamentally accurate and fair. The ultimate goal, as I think all the panelists here agree, is to advance technology. The only solution to climate change requires the significant advancement of technology. The debate, of course, is how best to do that. While our Commission had contentious discussions, I would say equal to those that I have heard take place in the Senate, one thing that we all agreed about very strongly and very early was that if we were going to move forward to address greenhouse gas emissions, as we believed was appropriate, the marketplace had to be the ultimate arbiter of which technologies moved forward, how quickly, and in what amount; that no matter how well intended or educated we all were, no 20 or 40 or 100 people could make the same kinds of decisions about how best to spend other people's money than 200 million people could make about how to spend their own.

So fundamentally, yes, we believe it is about sending a market signal, but also being realistic and not setting a signal so high that would make it politically irresponsible and create unacceptable dislocations.

Senator BINGAMAN. Well, let me just ask. The way you have chosen, the Commission has chosen, to try to send this market signal is by designing a cap-and-trade system and putting a safety valve in it and saying, in order to be in compliance it cannot cost you more than $7 per ton of carbon that you put into the atmosphere.

Just to be the devil's advocate here, are there not other ways that the Government could incentivize the private sector to promote and develop these new technologies through cost-sharing, R&D, or various other things that would also get us to the same place or perhaps get us there in a more direct way?

Mr. GRUMET. Senator Bingaman, I think there are certainly a variety of mechanisms, some of which you have heard described here today. Incentives sound lovely. We all like incentives. But fundamentally, somebody has to pay for those incentives, and in less attractive garb a massive Government program of incentives of the size which would be necessary to develop and deploy these technologies would require many tens of billions of dollars of taxpayer money, and we believe that the government is simply less efficient at choosing those solutions than the marketplace.

So it is possible. I am certainly interested in Dr. Smith's view of how much money it would take to advance the kinds of technologies at the pace that she believes is appropriate. We simply thought that it was not prudent, that it ultimately would be too costly, too inefficient, or some combination of both. So the marketplace had to be the dominant mechanism, but that mechanism could be augmented necessarily by raising some revenue to advance technology.

Senator BINGAMAN. So as I understand it, your Commission basically came down with the idea that the Government should do more to fund R&D of this type, but in addition to that or in parallel, we should enact some type of cap-and-trade system to incentivize or encourage or prod the private sector into doing much more in technology development than they otherwise would?

Mr. GRUMET. Senator, that is absolutely right. I think we all concluded quickly that the private sector, not the Government, was best capable of making these decisions, but that the Government needed to play a role, that placing the entire burden on shareholders was inappropriate and failed to meet the fairness test that Chairman Domenici addressed at the outset, that sharing that burden, dramatically finding ways to engage both the collective spirit and ingenuity of the private and public sectors, would have a synergistic benefit that we think is the ultimately coherent policy approach.

Senator BINGAMAN. Well, let me ask. One of the things that we sort of got hung up on when we were talking about this in the context of the energy bill, and very legitimately, questions were raised about how would—if you had a cap-and-trade system like the one you have described here, how would you allocate the credits or emissions credits, whatever, in a way that would be fair to everyone involved, would not advantage some sector of the economy over another?

Where are you and where is the Commission in its deliberations on that? Do you think that can be done? Is it still to be done in the future? Are you in the process of doing it?

Mr. GRUMET. Senator Bingaman, I think as you and Senator Domenici both expressed during the closing hours of this discussion on the energy bill, there are clearly winners and losers. There are winners and losers if there is a carbon price of zero, there are winners and losers if there is a carbon price of $7, $10, or $100.

One way that you can address those fairness issues is through the allocation of permits. It is important to stress that who you distribute the permits to in no meaningful way affects the overall economic costs of the program. Dr. Gruenspecht and CRA were able to analyze the total costs of our program with no knowledge of how the allocation would ultimately be meted out.

But to make the approach ultimately equitable and politically feasible, these are critically important decisions. I have to go off book here because our Commission did not try to specify a particular allocation formula, based on the view that that was ultimately such a political decision that we would really not be serving ourselves or the Senate very well by trying. We have started to host a series of very well attended workshops to try to bring together the various sectors of the economy and the interests to imagine different approaches. I think that it is surely possible to establish an equitable approach to allocation, just as was done in the acid rain program, and commend you for committing to consider these issues further. I think that will become ultimately the fundamental challenge, probably the last challenge in moving forward with legislation.

Senator BINGAMAN. Mr. Chairman, I notice the lights have not been on during my questioning. I do not mind continuing to ask questions, but I think I have been doing this for 5 minutes or more, so I will stop so others can go ahead.

The CHAIRMAN. I think you have, but we were going to let you go on for a little while longer.

I think that we will go on our side now. Senator Martinez was next, but he did not want to proceed.

Senator Thomas, you are next.

Senator THOMAS. Thank you, Mr. Chairman.

A very complicated issue and I appreciate all the detail that you have said. Would it be possible for you in two or three sentences to sum up your recommendation, where should we go from here, not go into all the details, but say what basically are you recommending for us to do? Would you each do that?

Dr. GRUENSPECHT. I am from the Energy Information Administration, so I am not recommending any actions.

[Laughter.]

Senator THOMAS. Well, thank you very much. I appreciate that.

Doctor?

Dr. SMITH. What I would like to say is that we need to first and foremost figure out how we are going to get to where we want to be, what sort of program is needed, how will we accomplish it, what will its targets be in terms of costs for reducing emissions——

Senator THOMAS. But that is, you are just asking questions. I want to know your answer. What would you do?

Dr. SMITH. I would design an effective R&D program that the Government could fund and get it started, and using that mission of the R&D devise some understanding of what sort of economy-wide emissions price should be placed on the economy today.

Senator THOMAS. I see. Given things like AML funds and so on, do you think the Government is prepared to handle that money properly?

Dr. SMITH. Sorry? What kind of funds? I did not hear.

Senator THOMAS. Well, just some of the funds that have not gone where they were intended to go when the Government is in charge.

Dr. SMITH. It is clear that funding of R&D needs to be a partnership of the private sector and the Government. The Government needs to sort out what amount of funding needs to flow and then find the means to support that funding.

Senator THOMAS. Thank you.

Mr. Grumet, you have talked in detail, but sum up where we are going.

Mr. GRUMET. In a couple of sentences, our Commission believes that we need to act as soon as possible to establish a modest long-term market signal that inspires the ingenuity of the private sector, support those exercises with continued government funding for longer term R&D, and link that program to efforts in developing countries so that we make sure that we ultimately have an effective and equitable global solution.

Senator THOMAS. Thank you.

Dr. MORGENSTERN. I would endorse a balanced approach involving a cap-and-trade with an R&D system which stimulates both private and public sector, quite similar to the NCEP, and that is my one sentence. My second sentence would be that there is really not that much difference between what Dr. Smith is proposing and what the NCEP is proposing, in the following way.

Dr. Smith in testimony recognizes that there is an economic logic to have a cap-and-trade approach. In Dr. Montgomery's testimony, which was not given today but was scheduled previously, he actually went so far as to name a number. His number was $4 a ton of CO_2. So we are really talking about a difference, in a sense, between $4 and $7. I would note simply for the record that there is a substantial literature that would support a $7 basis and there is really not a large difference in truth between the two.

Senator THOMAS. I notice you shaking your head.

Dr. SMITH. Dr. Montgomery did not suggest $4 per ton. It was a footnote that was an example of how you could back out what an appropriate spending would be once you know where you are headed with the R&D, and it was predicated on an example where the R&D would produce massive zero-emitting emissions reductions by 2050, I think, at a cost of $25 a ton.

So it was not a recommendation. It was an example. I believe I kept it in my testimony.

The other point is I am not recommending a cap-and-trade program. I am recommending an economy-wide price signal that would be predicated on the ultimate goal and mission of an R&D program once that is designed. So I am not debating the needs for some carbon price signal in the near term, but I am debating the way that it ought to be introduced and set up as a policy in the economy.

Senator THOMAS. Thank you.

Two comments as I close. One is that this trade thing seems to me, having been involved in world trade a little bit, what you are doing is giving away something that people that are not generating anything, that is not going to make any change particularly in the world.

The second is I see some of these numbers here in the reducing of coal, which is our largest fossil fuel resource. So when you look at energy issues on one side and these issues on the other, you have to have some balance in the kinds of fuels that we have available to keep people's lights on. So it is easy to talk about reducing all those uses, and at the same time what are you going to substitute it for?

So thank you all for being here.

The CHAIRMAN. Senator Salazar, I think I am going to go to Senator Murkowski, because she was here before you, if you do not mind.

Senator Murkowski.

Senator MURKOWSKI. Thank you, Mr. Chairman.

All of you have keyed in on the focus on technology, research and development. In the energy bill that was just passed, and signed by the President, we had a component or a section in there that related to the technology to provide for incentives that was, I guess if we had to characterize, our portion of the energy bill that related to climate change. There were those of us that looked at the legislation that Senator Hagel had put together in working with many of us and said, this is a step in the right direction.

Your comment on that? Is that sufficient? Do we need more? Dr. Smith, I think you said specifically that you think that policymakers have paid minimal attention to the R&D, the technology end of it. Are we going in the right direction with what we have passed?

Dr. SMITH. Are you speaking of title XVI?

Senator MURKOWSKI. I do not know what the title is.

Dr. SMITH. The part that passed——

Senator MURKOWSKI. Yes, yes.

Dr. SMITH. That is a start in the direction of defining a technology strategy, but it does not create the vision and mission of an R&D policies end point. Until we know where we are going, it is very difficult to organize an effective R&D program, let alone to determine how much should be spent on it.

So I think it had the right orientation of focusing on the R&D, but it did not provide and has not yet produced the vision of what needs to be accomplished in the R&D and then how to motivate our resources to get there.

I would say also, in the proposed amendment that reflects the NCEP proposals the subsidies do not reflect an R&D program. That is not what I mean by a revolutionary change in technology for providing energy over the next century.

Senator MURKOWSKI. Any other comments on that?

Mr. GRUMET. Senator, if I may. I think the energy bill is absolutely directionally correct. I agree with Dr. Smith on the need to do more. I also share the concerns of many that we are going to have a hard time finding all the money to support all the good things that the energy bill sets forth. So that is why this combination of market signal and an R&D program made sense to us.

To Dr. Smith's comments differentiating between breakthroughs and advances, I guess I am not clear about the technology. What I am clear about is no democratic process can determine a 100-year future to enable us then to move 100 years back and ask the right questions. Climate change is a century-scale problem. We are going to have to take a first step and then iterate from there. I believe that the energy bill and our Commission's support for advanced nuclear designs, for carbon capture and sequestration, for gasification, for dramatic increases in biofuels, to encourage the domestic production of more efficient transportation systems, and down the line are those gap technologies.

I would encourage the committee to look to the work of Dr. Sakalow from Princeton, who has identified 15 what he calls wedge technologies, the technologies I just mentioned and also efficiency technologies, natural sinks like agriculture and forestry. I think he makes a compelling case that if you look at those 15 technological categories, while ultimately the marketplace must choose among them, it provides a menu that I actually find quite encouraging.

Over the next 50 years, I think one can see optimism that both domestically and globally by moving forward with these technologies we can actually get to the goals that I think Dr. Smith and I share.

Senator MURKOWSKI. Dr. Gruenspecht.

Dr. GRUENSPECHT. Thank you. I would say that we in our analysis did a sensitivity run looking at different energy technologies—what difference would a different set of technologies make. It does make a considerable difference to the results, both with and without additional policies. So there is no question that technology matters.

We do sometimes have trouble relating changes in legislative provisions to changes in technology. A lot depends on what happens with a program. I think one of your colleagues mentioned earlier that some programs get run well, some programs do not. There are also issues of what is the amount of actual appropriations—is it just money moved from one category to another category—so you close an old program and start a new program. All those questions come up.

So it is very hard for us to look at the effects of a particular program, particular legislative language, and say what difference that makes to technology. But there's no question that technology makes a difference.

I would also note that the Department of Energy has a climate change technology program. I think it is also referenced in the energy bill. They do have a vision and framework for strategy and planning that is on the web site, and it is my understanding that they will put out a strategic plan, a long-term strategic plan for public comment, some time in the near future, that I think does address some of the—or may address some of the issues that Dr. Smith raised.

So I think there is an effort to provide a road map, if you will, that the Department will be coming forth with in the fairly near future. That might be of interest to you.

Thank you very much.

Senator MURKOWSKI. Thank you, Mr. Chairman.

The CHAIRMAN. Senator Salazar, I am going to ask a few questions since I did not ask any. Then you are next. Is that acceptable to you?

Senator SALAZAR. Yes.

The CHAIRMAN. Let me talk a minute about the Kyoto since we get that thrown at us quite often. First, I would like to reiterate an observation that seems to evade most people that criticize America, that the decision about Kyoto was not made solely by a President. The U.S. Senate voted and told the President of the United States, do not send that treaty up here, because we would not approve it, and that vote was 98 to zero. So everybody should know that for every time Europeans decide to chastise President Bush about it they should add, and the U.S. Senate decided it would not work.

Now, having said that, what would a reduction of emissions to 1990 levels do to the U.S. economy, either of the economists here, or you? It is my understanding that only two members of the European Union are likely to meet Kyoto commitments. If mandatory controls are deemed to be the answer to the climate change problem, why are such controls not working in Europe?

Dr. GRUENSPECHT. We at the Energy Information Administration back in the late 1990's did some analysis of the Kyoto Protocol and those analyses suggested, I think, pretty significant economic impacts. I should also point out, though, that various EIA analyses are not directly comparable for several reasons.

One, the reference case used as a baseline for the analysis has changed a lot since that earlier work was done. Second, our Kyoto analysis did not look at non-CO_2 greenhouse gases, which we know from the analysis we did for the NCEP proposal requested by Senator Bingaman, make a difference. Third, there is frankly uncertainty in interpreting what the Kyoto Protocol itself means.

Let me give you an example. There is a period from 2008 to 2012 where there is an emissions limitation under that agreement, but the question is what do you assume beyond 2012? Do you assume it stays at the same level? Do you make an assumption about what the negotiators in that framework will agree to beyond 2012? So there are lots of open questions.

But I take your point that certainly a large emission reduction in a short period does tend to produce much larger economic impacts.

The CHAIRMAN. Anybody else want to? I do not want to spend all my time on Kyoto. It just irks me that it is constantly referred to by Europeans, even with reference to the hurricanes. It is just amazing that they are talking about, since America did not sign the Kyoto agreement, we are reaping what we are entitled to in hurricanes. I do not know how anybody can even say such a thing.

Yes, Mr. Economist.

Dr. MORGENSTERN. Well, the only thing I would add to Dr. Gruenspecht's point is that the reductions required for the Europeans are in fact lower than they were for the United States, so that it is not even fair to make that comparison about what the impact is on them as opposed to what it is on us.

The CHAIRMAN. A very good point.

The other point, I do not want anybody, including you, Mr. Grumet, anybody working on this approach, to think that we ought to look at acid rain. We should, but that is an easy comparison. You understand that the area of involvement is very minor in terms of the numbers of participants in the SO_X problem. There are just two major ones, whereas when you are trying to put together all the players in this area there are many, many scores of them. So it might be a similar idea, but it certainly is not a similar problem. Is that a fair statement?

Mr. GRUMET. Mr. Chairman, I think that is exactly right. I think that the Energy Commission's approach tries to directly recognize that. I think there was no argument, really significant argument, that you needed a safety valve on the SO_2 proposal. It was manageable. The technologies here are greater, I think much greater, and I think the response needs to be different.

The CHAIRMAN. I have got three quick questions. The next question has to do with an appropriate incentive to move the technology. I am listening attentively to the difference in opinions here on how we move the technology. Dr. Smith, I understand yours, and I understand yours on behalf of your Commission. But let me ask, in the energy bill we recognized that it probably would be difficult for the U.S. Government to appropriate money for the experimental technology, say three or four major new projects in the gasification, sequestration area. So we provided an incentive provision that says two ways to do this. One is appropriate and the other is by a new type of loan that the Federal Government could make on a 75-25 basis at reduced interest rates, with insurance being paid by the applicant so that it is cost-neutral.

Is that an incentive in anyone's opinion for anybody to use that, or is that not sufficient?

Dr. Smith.

Dr. SMITH. That is an incentive to implement a technology that can be implemented today, that exists at a near-reasonable but still too high a cost to be justified in the marketplace. When I speak of R&D, I mean what may involve basic research, basic scientific research, to make breakthroughs that would allow technology to come in at maybe half the cost of what can be done with the current technologies today at some price that is in the realm of too costly for the marketplace, but may be subsidizable.

The CHAIRMAN. Anybody else have a comment on that?

Mr. GRUMET. Mr. Chairman, I think the tax credits are very thoughtful and appropriate mechanisms. I think those will encourage IGCC. I just have maybe lower expectations than Dr. Smith. I think deploying a fleet of carbon-sequestered IGCC facilities in the next 20 years is an incredible accomplishment that we should strive toward.

The CHAIRMAN. Well, that is why we put it in there. We thought that. She may be right, though, and we have to have another thing going on basic. And we do not put enough money in basic research, so I do not know where we would ever get enough here, unless it came from the carbon that you are speaking of, the carbon, the assessment of a carbon tax, which seems to be anathema.

Dr. Smith, you indicated—you had an observation: For the near-term emissions reductions, the most cost-effective emission reduction available today are in the developing countries. I think you said that. Placing a high priority on near-term control policies to bring about changes in how energy is used in developing countries is most important, as you indicated.

Would you elaborate for us on how we might help get that done, or is that up to somebody else and it will happen or not without us?

Dr. SMITH. One of the greatest barriers that we have identified—and my colleague David Montgomery has been working on this one at some length in the last few years. One of the greatest barriers to getting the technology into other countries is simply the basic rule of law, property rights, and inviolability of contracts and enforceability, general freedom of markets, and even pricing energy at its cost.

If these things could be changed, then better investments can be made with today's technology. Even with the efficiency standards that we have today, those could be better deployed into these developing countries and achieve much greater reductions in emissions globally, which is all that we really care about, than we can achieve in our own country at that cost.

The CHAIRMAN. So those countries would have to do that, make those stabilizing decisions?

Dr. SMITH. It is a challenge. Again, the Hagel-Pryor amendment that passed into law with the Energy Policy Act has some provisions to move in that direction. It is a very good first step. It identifies the right challenges, I think. But it is still going to be a challenge to implement.

The CHAIRMAN. My last question goes to you, Mr. Grumet. You are busy having task force, or whatever you call them—what do you call them?

Mr. GRUMET. Workshops.

The CHAIRMAN. Workshops, trying to address the issues that Senator Bingaman and I introduced on the floor, that you had a great idea and we introduced a great bill, but how do you implement it? Are those workshops aimed at trying to fill in some gaps as to what might be a fair way to implement?

Mr. GRUMET. That is certainly the aspiration, Chairman Domenici. I should say, though, that I think we are realistic in the expectations we have for 3 or 4 half-day sessions. We found that there was a dramatic degree of misunderstanding about the different options and I think our hope was actually to bring people together so that we could then fight more effectively before you in the future.

We are not optimistic or even seeking to bring together a consensus, but I think that we can elevate the understanding so that we can have a more effective real debate.

The CHAIRMAN. It seems to me those stakeholders who are participating may be the ones who come up with the answers.

Mr. GRUMET. That would certainly be our hope.

The CHAIRMAN. Senator Salazar.

Senator SALAZAR. Thank you very much, Chairman Domenici and Senator Bingaman, for holding these hearings on this very, very important issue.

I have two quick questions. The first relates to agriculture and how the agricultural community might actually benefit from a cap-and-trade system and the second question has to do with the EU and their cap-and-trade program and how that is working. I am going to ask the questions and let you comment on both of them.

First of all, with respect to my question on agriculture, it seems to me that farmers in Idaho who are growing potatoes by the thousands and thousands of acres or farmers in my State that are growing alfalfa could see significant positive impacts from being involved in a cap-and-trade system, because they obviously are consuming large amounts of carbon dioxide in the growth of their plants.

I am one of the defenders of our energy bill because I think it did for the first time in our country push forward renewable energy as a major component of our future energy policy, and I think that is creating opportunities and will create opportunities for rural America and for agriculture. But I also see the issue of how we deal with climate change as creating an opportunity for farmers who are consuming so much carbon dioxide in their plants.

I would like you to comment, Mr. Grumet or Dr. Smith, Dr. Morgenstern, whoever of you wants to comment on that issue of agricultural opportunities as we deal with the issue of climate change. Then, second, if you would also comment on how the European Union cap-and-trade system is in fact working, since it is up and running.

Mr. GRUMET. Maybe I will start with agriculture and then turn it over to somebody else to talk about the EU. Senator Salazar, I think your instinct is exactly right that, given a rational incentive, there is money to be made in agriculture for lower carbon activities. I think it is also particularly important to think about this as we see that the commodity price supports and the Doha Trade Round and others are now being called into question. We are sensing a growing interest in the agriculture community, thinking about how in fact carbon-smart activities could also be a profit center.

I just point to two examples. Obviously, if there is a value to reducing a ton of emissions that would provide a significant incentive to sequester carbon through more intelligent agricultural practices. In addition, farms have a tremendous opportunity to provide energy and do so in a low-carbon, low-cost way. I think we were very pleased to participate in a workshop that Senator Craig held talking about how to bring cellulosic biomass from wheat straw into the marketplace. What we find, of course, is that that product, while desirable, is more costly than gasoline. It is also far lower in carbon emissions. If there was a value in the marketplace to lower carbon emissions, it would provide an additional incentive to those thoughtful types of breakthrough technologies that I think we all want to see advance.

Senator SALAZAR. Mr. Chairman, I had the opportunity to be in Europe last week to participate in a discussion of the EU system. I am not an expert on it, but I can report a little bit about some of the results. It is operating, as you know, in two phases. There is a warmup phase for the first several years and then beginning in 2008 is when the larger version goes into place.

At this point they have over 11,000 sources actually participating in the program. All 25 countries have actually set up programs and have approved plans. There have been a fair number of trades. There has also been a fair amount of price volatility. The range of prices has ranged from somewhere around eight euros per ton of CO_2 up to almost 30 euros per ton of CO_2. Currently it is around 22 or 24 euros.

It is interesting to try to draw some lessons from their experience for our experience. Of course, everything is still in the early phases and it will undoubtedly evolve. But I think there is a couple of points that one can make. First of all, the price volatility that they have experienced, which in many ways is tied to changes in weather patterns and fuel market changes, would probably not be experienced under the NCEP proposal, simply because the safety valve would undoubtedly have dampened that. So that is one difference.

Second, there have been some complaints in Europe raised about potential windfall profits in their system, and in part that may be tied to the allocation system. Undoubtedly, Congress would do a fairly detailed—would make fairly detailed decisions about allocation that I would expect would obviate that problem.

Senator SALAZAR. Dr. Morgenstern, what has caused the volatility in terms of price from $8 to $30?

Dr. MORGENSTERN. Well, the experts in Europe believe that it has to do with weather, different expectations about weather, and frankly fuel volatility. International oil market prices and other fuel changed have been the largest driving forces. That is what they have explained to me and I am just reporting that to you.

But the safety valve, as I say, had it been in place would have dampened that and would have prevented that from occurring.

Senator SALAZAR. In the European cap-and-trade market, what has been the experience of agriculture with respect to that market? Are there programs under way that agriculture is benefiting from because of the cap-and-trade system there?

Dr. MORGENSTERN. Well, that is a very interesting point. The design of the system as I understand it does not include agriculture at this point, and in fact the design of the system only covers one-half of the total emissions in the economy. So we could actually—so a sector like agriculture is not able to participate in the I system. In the NCEP proposal it would be able to participate.

It is interesting in terms of the EU compliance. Because they have only about less than half really of their economy, the emissions, covered by this trading system, it is very likely that the other half will in fact not make the targets, and we may have a system where the trading system seems to be highly successful, but the overall outcome in terms of the EU meeting its targets may not come to pass. Obviously we do not know. They may be able to buy tons from Russia or something. I do not know how that will play out.

But sectors like agriculture or sectors like transportation, which are not able to participate by design in their system, are reportedly having the most difficult time meeting their targets.

Senator SALAZAR. Thank you very much.

Senator CRAIG [presiding]. Thank you.

We have a vote under way, I think, now. Is that correct? Two votes stacked. The chairman has gone to vote and I think plans to return, so we will move on for a time.

Senator Talent.

Senator TALENT. I will be brief, Mr. Chairman.

Mr. Grumet, if we adopted NCEP how much would it reduce global warming? How many degrees reduction would we get?

Mr. GRUMET. Senator Talent, I am guessing you know my answer is that the NCEP proposal in the first 10 years would have no meaningfully ecologically visible impact on the globe's warming, nor would Kyoto, nor would McCain-Lieberman or anything else.

Senator TALENT. Maybe after the 10 years, what will we get?

Mr. GRUMET. All of these are century-scale efforts. I think that there is a recognition in the scientific community that if we allow greenhouse gas concentrations to double or triple we may find very unfortunate effects that would result from a three to five degree increase in temperature. The goal is to mitigate that.

Senator TALENT. After 10 years, do we know?

Mr. GRUMET. Senator, we will never know. I think that is a fair——

Senator TALENT. Fair enough.

Just to make this brief, because maybe Senator Smith wants to go before the vote, I think the NCEP concept explicitly anticipates that after 5 years or 10 years we will consider another step. Is that correct?

Mr. GRUMET. Absolutely, sir.

Senator TALENT. Now, here is my concern about how this might operate on the ground. If you are a company and you are thinking about investing in a chemical plant or a refinery—and we certainly need more refinery space—and Congress has passed NCEP, maybe you can quantify the costs of NCEP. But what you know is that in passing it, Congress explicitly anticipates doing something else 5 years or 10 years down the road. You do not know—as a matter of fact, what is being I think marketed as a virtue of NCEP is that we do not know, that we will make some adjustment down the road.

So you are thinking of investing hundreds and hundreds of millions of dollars in a plant. You are going to have to get a rate of return on it. You certainly do not want a financial disaster, and you have this thing hanging out there. Now, do you not think that under those circumstances you might consider, you know, we can make a similar investment in China and we have a pretty good idea what our costs are going to be there?

Mr. GRUMET. Well, Senator, certainty in terms of projecting atmospheric or global temperatures or business is always a desire and never an option. The question that our Commission dealt with in terms of business certainty was, was there more certainty in the status quo, where people have all kinds of different proposals, many much more aggressive than ours, many much less aggressive, and we kind of have a spiritual fight about are we going to do it all or do none of it.

I think our group came to conclude that setting a path forward that had a gradual program, that recognized that we had to slow emissions before we sought to stop and ultimately reverse them, that obligated the Congress of the United States to affirmatively engage before those changes were made, that had a set of dials for an intensity reduction so you would not have discontinuities and big jumps, I think our group thought that provided more certainty than rolling the dice and seeing what happened next.

Senator TALENT. When I chaired the Small Business Committee in the House I had to constantly remind myself, we love small business because it produces jobs, it hires people, it produces technological innovation, but nobody ever started a small business to create jobs. They start a small business or, for that matter, they make an investment as a big business in order to get a return on the investment.

I just think we have to be very careful. I understand what you are doing and I think from our perspective here it seems to make sense. We talk with all the stakeholders, we have this initial step. My concern is on the ground it is going to produce actually more investment precisely because of the uncertainty, it is going to produce more investment where they do not care about global warming, and we may end up with more greenhouse gases and fewer jobs, and that would be the one dumb thing to do, would be to hurt the economy and get nothing in favor of it.

I understand what you are doing. I am just concerned that the uncertainty may have exactly the opposite of what you intend.

Thank you, Mr. Chairman.

Senator CRAIG. Thank you very much.

Senator Smith, I got here before you did. I am going to ask one question. I think we can get both of our questions in.

I wanted to ask this of EIA. Figure 4 in your charts, doctor. I find it very interesting as you look at the spread of savings and usage, and figure 4 represents that item, generating capacity additions by type 2004 through 1925. I have traveled the world about as much as anybody on the climate change issue. I do not know how many COPS I have been to, but it is a fascinating cottage industry to watch. Now, having said that, I do not mean that as a slam at all. But there is a great industry that has grown up around climate change itself, for better or for worse.

But there is a reality out there and the reality is that there are some technologies, if fully implemented, could have tremendous effect on emissions. One of them is nuclear. We worked very hard to incentivize new nuclear in the energy bill and, while I have not read all of your testimony, I would hope that you would analyze and make a reasonable argument that if we fully implemented and fully fund what we have just done as a country we could move ourselves ahead in a dramatic way, but most important is that we would also build technologies that were available to the world to use.

So I am sitting with the Chinese representative in Buenos Aires. He talks about 100 new nuclear plants, 100. They are still dominantly coal. They are going to build a lot of coal. We are now working with India. They could come on line. We have at least four on the drawing boards in this country now that could be pouring concrete by 2008, could be on line by 2015. Yet nothing shows up here in your charts as to increased generating capacity as it relates to nuclear. Or am I just missing it?

Dr. GRUENSPECHT. First let me say, I am a retiree from the cottage industry that you mentioned having to do with global warming. So I was quite involved in the early 1990's, less involved today.

I would say that this is an analysis of the NCEP policy proposal.

Senator CRAIG. So I am directing it at the wrong——

Dr. GRUENSPECHT. No, you are directing it correctly, I think. The NCEP policy proposal had a modest incentive, I think, that in our estimation produced one additional nuclear plant, and there it is in our chart.

This analysis, I will say, was done before the passage of the energy bill and, as you mentioned, the energy bill has some very significant incentives for nuclear, including a production tax credit. That is a very significant incentive for up to 6,000 megawatts. It has the insurance proposal that the administration advanced. It has title 17. Presumably, the incentives there, which are very open-ended, could be used for nuclear.

What I would say is that this chart does not reflect the energy bill. It reflects the incremental effect of the NCEP proposal. We will in fact at EIA need to look at the energy bill in the context of our next annual cycle of long-run projections, and those are very significant provisions and those provisions would have an effect. But this analysis and the testimony was about the NCEP proposal.

Senator CRAIG. I got you, I got you.

I am a little frustrated that we are still—and we should, I guess—be hypothesizing where the future is. I do believe there is a responsibility, though, to suggest, those of you who are advocates, that what we have just done is a significant work and we ought to be fully funding it and implementing it, because there are technologies in there that spread across the spectrum into the world at large, that are going to be very beneficial in the long term, while we still debate conceptual ideas of how to do other things.

Dr. GRUENSPECHT. Let me just say one more thing. Obviously, EIA has no crystal ball about what the funding will actually be. But at least with respect to the production tax credits, that is not a proposal that requires funding as we understand it.

Senator CRAIG. That is correct.

Dr. GRUENSPECHT. And we will need to deal with that.

Senator CRAIG. Senator Smith.

Senator SMITH. Let me begin my comments by admitting to our questioners—thanking you for being here, or our panelists, but admitting to you that I am suspicious of government-planned markets. Last week I was one of the few Republicans who voted against the cap-and-trade system for mercury that was proposed by the Bush administration. The environmentalists loved my vote, but now they want me to vote for a cap-and-trade system as to carbon.

How do you reconcile that?

Mr. GRUMET. Senator, I will wade into these delightful waters. I think that the general conclusion that our Commission brought to this discussion is that market-based programs are more efficient and more effective and should be used everywhere possible, with one exception. That exception is when the use of the free market creates distributional impacts that concentrate pollution in one place and not another.

I take no position on the mercury decision, but note that, mercury being a neurotoxin, there are concerns about market trading in mercury, which I assume attach to your concerns and your vote. Carbon being harmless to breathe, it is actually the perfect pollutant in which a market-based system can provide you with all the incentives with none of the anxieties about those distributional impacts.

So I imagine that is the basis of the differentiation.

Senator SMITH. I guess my concerns or my suspicions about the EU's approach and the difficulties they are running into, my suspicions I guess are further heightened by all of this.

But when it comes to carbon, I live in a State where every year we burn up tens of millions of acres of trees. 2 years ago—I think it was 2 years; maybe it is 3 now—we had the Biscuit Fire. It burned up more land than there is acreage in the State of Rhode Island. The amount of carbon that that put out was 40 million tons.

I know you are not foresters. 40 million tons, just that right there, that is about 10 percent of the emissions of all the coal plants in America. I guess my question is what is the best forest policy? When you think of requestration, should we just leave these carbon moonscapes as they are and let natural regeneration go? Or would we be better off in terms of global warming to replant these areas, knowing that that takes half the time that the other takes?

Dr. SMITH. May I comment?

Senator SMITH. Yes.

Dr. SMITH. First I would like to point out that 40 million tons is about our estimate of how much the NCEP proposal would produce in reduction in 2010. So you are right that it is a very large amount, but it is also a very small amount that we are saying would occur under the NCEP proposal. Effectively we are saying it will give us the equivalent of one less forest fire of that sort.

On the other hand, it certainly makes sense to reforest where one has burned down if that is the best use of the land. That will certainly sequester over time some of the emissions back in.

Senator SMITH. So replanting is good for global warming purposes?

Dr. SMITH. Replanting generally is good for reducing carbon emissions if it makes sense as a land use, too.

Senator SMITH. Any other comments on that?

Mr. GRUMET. I come from a part of the country that is largely paved, so I am not going to offer my thoughts about forestry. I would just note that Dr. Smith chose to identify the first year of this program, which begins very gradually. In 2025 our modest program is expected to reduce a billion tons of carbon a year. So 40 million is a big number, but I think in context it is certainly not fully offsetting what we would consider a mandatory economy-wide reduction program.

Senator SMITH [presiding]. It is interesting you say that. This is no criticism, but it is the areas that are all paved over that are telling the areas where forests how to run their forests.

I think all of my colleagues have left to vote and I need to do the same as well, because I think it is just about to end. So let me—I am given instructions that we are adjourned.

[Whereupon, at 11:41 a.m., the hearing was adjourned.]

APPENDIXES

Appendix I

Responses to Additional Questions

Responses of James W. Hurrell to Questions From Senator Bingaman

Question 1. Over the last several decades, anthropogenic emissions have "substantially contributed" to the increase in average global temperatures. Upon receiving a question from one of the Senators, one of the panelists suggested that "80 percent" of the warming was due to human activities. Do all the panelists agree? Please provide information as to how this estimate was derived.

Answer. The strongest evidence to support this statement comes from numerical experiments performed with state-of-the-art global climate models. These models encapsulate the current understanding of the physical processes involved in the climate system, the interactions, and the performance of the system as a whole. They have been extensively tested and evaluated using observations. Today's best climate models are now able to reproduce the climate of the past century, and simulations of the evolution of global surface temperature over the past millennium are consistent with paleoclimate reconstructions.

As a result, climate modelers are able to test the role of various forcings in producing the observed changes in global temperature. Forcings imposed on the climate system can be natural in origin, such as changes in solar luminosity or volcanic eruptions, or human-induced, such as increases in aerosol and greenhouse gas concentrations in the atmosphere.

Climate model simulations that account for such changes in forcings have now reliably shown that global surface warming of recent decades is a response to the increased concentrations of greenhouse gases and sulfate aerosols in the atmosphere. An example, from a climate model simulation performed at the National Center for Atmospheric Research (NCAR), is provided in Figure 1.* When the model is integrated forward in time over the 20th century with only information on imposed natural forcings, there is no discernible trend in global surface temperatures over the last several decades (blue line). When changes in greenhouse gas and aerosol concentrations are added to these natural forcings, however, the model not only simulates an increase in global surface temperature (red line), but it almost exactly reproduces the observed rate of change (black line). Numerous simulations for each case are run, and the solid lines represent the mean while the shaded regions indicate the "spread" about the mean. This spread reflects intrinsic natural climate variations arising from purely internal atmospheric processes as well as from interactions among the different components of the climate system, such as those between the atmosphere and oceans or the atmosphere and land.

Such results, which have also been produced by several other independent modeling groups, increase our confidence in the observational record and our understanding of how global mean temperature has changed. They also indicate the time histories of the important forcings are reasonably known, and the climate processes being simulated in models are adequate enough to make the models very valuable tools for investigating the causes and processes of past climate variations as well future climate change.

Question 2. We received testimony that sought to distinguish between average global temperature changes causes primarily by anthropogenic emissions and local/regional temperature changes caused at times by natural variation. Please explain in greater detail.

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*Figures 1 and 2 have been retained in committee files.

Answer. Global average temperature increases in recent decades are primarily due to changes in anthropogenic forcings (*Question 1*). Evidence for a warmer world is also reflected in other independent measures as well, as documented in my written testimony. Some of these are regional in character, such as: (1) the rapid melting of glaciers in non-polar regions around the world; (2) decreases in the areal coverage and thickness of Arctic sea ice, especially during summer, and of snow cover over northern continents; and (3) reductions of a few weeks in the annual duration of northern lake and river ice cover. Yet, in spite of this and other evidence (e.g., rises in global sea levels) that gives a collective picture of a warming world, the magnitude of the anthropogenic influence on regional climate remains uncertain. A principal reason is because the effects of human activities are superimposed on the background "noise" of natural climate variability, which can be very large regionally.

Global warming does not mean that temperature increases are spatially uniform or monotonic: some places warm more than the average and some places cool. Land regions have warmed the most (0.7° C since 1979), with the greatest warming in the boreal winter and spring months over the Northern Hemisphere (NH) continents. Regionally, winter (December through March) temperatures have been 1-2° C warmer than average over much of North America and from Europe eastward to Asia over the past two decades, while temperatures over the northern oceans have not warmed as much (Figure 2). This pattern is strongly related to decade-long changes in natural patterns (or modes) of the atmospheric and oceanic circulation. In particular, changes in the behavior of the El Niño/Southern Oscillation (ENSO) phenomenon and the Pacific Decadal Oscillation (PDO) have contributed substantially to the regional cooling of the North Pacific Ocean and the warming over western parts of North America, while changes in the behavior of the North Atlantic Oscillation (NAO) have driven much of the warming over Europe and Asia.

Changes in anthropogenic forcing may affect these modes, however, so quantifying the anthropogenic and natural components of the observed warming on regional scales remains a difficult and critical research question. For instance, several recent studies have concluded the temporal behavior of the NAO in recent decades is outside the range of natural variability, and moreover that this unusual recent behavior is linked to the (anthropogenic) warming of the tropical oceans. Similarly, some have argued that the recent behavior of ENSO is inconsistent with natural variability. Yet, attribution remains uncertain.

Many global climate models, for instance, project changes in the statistics of ENSO variability with global warming, specifically of greater ENSO activity marked by larger interannual variations relative to the warmer mean state. More El Niño events would increase the probability of weather regimes that favor the regional patterns in Figure 2; yet, the details of ENSO are not well enough simulated in climate models to have full confidence in these projected changes, in part because the positive atmosphere-ocean feedbacks involved with ENSO mean that small errors in simulating the relevant processes can be amplified.

Thus, while it is likely that changes in ENSO, the NAO and other natural modes of climate variability will occur as a result of anthropogenic climate change, their nature, how large and rapid they will be, and their implications for regional climate change around the world remain uncertain.

Question 3. Please explain the meaning of 'scientific consensus' and comment on the status of the science of climate change in the scientific and academic community.

Answer. A key aspect to scientific consensus is the building of a consensus and, thus, the process. In the case of the Intergovernmental Panel on Climate Change (IPCC), the process is very open and inclusive.

The mandate of IPCC is to provide policy makers with an objective assessment of the scientific and technical information available about climate change, its environmental and socio-economic impacts, and possible response options. The IPCC reports on the science of global climate change and the effects of human activities on climate in particular. Each new IPCC report reviews all the published literature over the previous 5 years or so, and assesses the state of knowledge, while trying to reconcile disparate claims, resolve discrepancies and document uncertainties. For the 2001 Third Assessment Report (TAR), Working Group I (which deals with how the climate has changed and the possible causes) consisted of 123 lead authors, 516 contributors, 21 review editors, and over 700 reviewers. The lead authors all have to be satisfied with the content of the report and the wording. There are also several independent reviews at various stages, including a full governmental review, and all comments must be addressed and documented by the review editors. Final approval is through an intergovernmental meeting. This means that the report cannot be selective in what it deals with. It is a very credible document, and very much represents a consensus.

The TAR concluded that climate is changing in ways that cannot be accounted for by natural variability and that "global warming" is happening. There are still and will always be climate change skeptics, but the vast majority of reputable scientists accept and agree with the major conclusions of the IPCC reports.

Question 4. What is "abrupt climate change?" Can you identify any potential thresholds that might be crossed if insufficient action is taken to control CO_2 emissions? For example, I have heard that beyond certain temperature increases, large ice sheets could collapse, leading to huge increases in sea level. Can you comment on this and other potential thresholds?

Answer. There is an abundance of scientific evidence that shows major and widespread climate changes have occurred with startling speed. For example, roughly half of the warming of the North Atlantic Ocean since the last ice age was achieved in only a decade, and this warming was accompanied by significant changes in climate across most of the globe. Research over the past decade has shown that these abrupt—or nonlinear—climate changes have been especially common when the climate system was being forced to change most rapidly. Thus, the rate of buildup of carbon dioxide in the atmosphere may increase the possibility of large, abrupt and unwelcome regional or global climate events.

The mechanisms of past abrupt climate changes are not yet fully understood, and climate models typically underestimate the size, speed and extent of those changes. Hence, future abrupt changes cannot be predicted with confidence. Yet, because of greenhouse warming and other human alterations of the earth system, and the long lifetime of carbon dioxide in the atmosphere, certain thresholds are likely to be crossed and we will not know we have crossed them until it is too late to alter the outcome.

So what can we do in the face of such uncertainty? Someone recently brought to my attention the analogy of buying insurance. One does this not because it lessens the chance of some terrible event, but because it smoothes out the financial impacts if a catastrophic event does occur. In the case of abrupt changes in climate, buying insurance—in the form of sound climate policy—not only reduces the risk of severe climate impacts but also smoothes out the risk of having to make abrupt changes in policy, which we know are costly.

Question 5. Can you tell us something about the time horizon for stabilizing climate, given how long carbon dioxide remains in the atmosphere? Do we need to begin to control emissions now or can we wait?

Answer. Because of the long lifetime of carbon dioxide and the slow equilibration of the oceans, there is a substantial future commitment to further global climate change even in the absence of further emissions of greenhouse gases into the atmosphere. Several modeling groups have performed "commitment" runs in order to examine the climate response even if the concentrations of greenhouse gases in the atmosphere had been stabilized in the year 2000. The exact results depend upon the model, but they all show a further global warming of about another 0.5° C, and additional and significant sea level rises caused by thermal expansion of the oceans by the end of the 21st century. Further glacial melt is also likely.

There is now also better quantification of the climate system response to different emission scenarios (stabilization at 550, 690 and 820 ppmv concentrations of carbon dioxide by the year 2100). All global climate models contributing the Fourth IPCC Assessment Report (due to be published in 2007), for instance, produce similar warming trends in global surface temperatures over the next few decades, regardless of the emissions scenario. Moreover, nearly half of the early 21st century climate change arises from warming we are already committed to. By mid-century, the choice of scenario becomes more important for the magnitude of warming, and by the end of the 21st century there are clear consequences for which scenario is followed.

Question 6. Given that there is still some uncertainty about the details of future warming, how should such uncertainty be dealt with in designing policy responses?

Answer. There is indeed uncertainty in the details of future warming. Climate models are not perfect, and uncertainties remain. For instance, the precise nature of aerosol/cloud interactions and how aerosols interact with the water cycle remains a major uncertainty in our understanding of climate processes and, thus, their representation in models. Yet, the ability of these models to simulate the past record (Figure 1) means that the processes being simulated are adequate enough to make the models very valuable tools. Moreover, in spite of uncertainties and differences among models, they produce a number of consistent results concerning future climate change (see *Question 5* as well as my written testimony).

Based on this and other evidence, I believe there is a clear need to begin to reduce emissions immediately. While some changes arising from global warming might be benign or even beneficial, the rate of change projected exceeds anything seen in nature in the past 10,000 years and is apt to be disruptive in many ways. Economists have analyzed the costs of various policy responses and they tell us that the most cost-effective emission trajectories involve starting now to control emissions. Further delay will be costly.

Question 7. How do we know that emissions of carbon dioxide and other greenhouse gases are causing Earth's temperature to rise, as opposed to other factors that we have no control over; such as sun spots? Some assert that an increase in solar irradiance is the main cause of the Earth's current warming trend. Therefore, reducing fossil fuel emissions would not impact the Earth's temperature.

Answer. Although there is little doubt that the sun's radiant output impacts the Earth's climate on both decadal and centennial time scales, there is no credible evidence to suggest that an increase in solar irradiance is the main cause for the recent warming trend. This is addressed in my response to Question 1.

Question 8a. There are some who question the veracity of the assertion that the earth has warmed substantially over the last century. Arguments typically fall into three categories. It would be useful if you would address each in turn:

Urban Heat Island Effect. This is the claim that the underlying temperature data is tainted by the proximity of data-generating thermometers to cities. As urban areas have grown over the last fifty years, the air temperatures around these cities have increased due to larger amounts of heat generating substances like rooftops and roadways. Scientists claim to have corrected for the urban heat island effect. How was this done, and how can we be sure that it was done correctly?

Answer. While amplified warming does occur in cities and is an important local phenomenon, a number of independent and recent studies have shown that urbanization is a negligible effect as far as continental-and hemispheric-space averages are concerned. Over land, temperature data come from fixed weather observing stations with thermometers housed in special instrument shelters. Records of temperature from many thousands of such stations exist. Some are in urban areas. Many are not.

One concern regarding the construction of global temperature records is the variety of changes that may affect temperature measurements at an individual station. For example, the thermometer or instrument shelter might change, the time of day when the thermometers are read might change, or the station might move. These problems are addressed through a variety of procedures (for example, checking for consistency with data from neighboring stations) that have proven to be very effective. Other, perhaps more subtle influences (e.g., urbanization) are addressed either actively in the data processing stage or through dataset evaluation to ensure as much as possible that the data are not biased. For instance, several studies have compared global surface temperature time series made up of only rural stations with the "standard" global temperature time series, only to find out that there is no significant bias. The IPCC (2001) stated that urban heat island effects could contribute no more than six percent of the rising average temperature trends in recent decades, and a National Academy study of the surface temperature record concluded that the global surface temperature trend accurately reflects warming.

Question 8b. Satellite and Airborne Balloon Data Contradict Surface Temperature Readings. Global mean temperature at the earth's surface is estimated to have risen by about half a degree F over the last two decades. On the other hand, satellite measurements of radiances and airborne balloon observations indicate that the temperature of the lower to mid-troposphere (the atmospheric layer extending from the earth's surface up to about 8 km) has exhibited almost no change during this period. Please explain whether this discrepancy is, indeed, real and how to account for it.

Answer. I argue that there is no contradiction, and the reasons why are provided in my written testimony. There are several key points:

- The satellite and surface data differ in what they measure: surface thermometers measure the air temperature at the Earth's surface, while the satellite measurements in question infer temperatures of different broad layers of the atmosphere which respond differently to natural climate variations such as ENSO, greenhouse gases and other factors that influence climate.
- A chronic difficulty in obtaining reliable climate records from satellites has been changes in instruments, platforms, equator-crossing times, and algorithms. The microwave sounding unit (MSU) tropospheric temperature record has overcome some of these problems, but how transitions between different satellites are dealt with and other biases in the data result in a range of global trend estimates. Several groups have analyzed the data, and over 1979-2004 all data

versions show warming; however, the trend estimates range from 0.04 to 0.17° C decade^{-1}. Such differences highlight the issue of temporal homogeneity in the satellite data.

- Because about 15% of the MSU signal for middle tropospheric temperature actually comes from the lower stratosphere, the real warming of the middle troposphere is greater than that indicated by the MSU data sets. This has been confirmed by new analyses that explicitly remove the stratospheric influence, which is about −0.08° C decade^{-1} on middle tropospheric MSU temperature trends since 1979.
- By differencing MSU measurements made at different slant angles, new data records can be created that are weighted more toward the lower troposphere. The latest product exhibits a warming trend that is 0.2° C decade^{-1} larger in the tropics (where the largest "discrepancy" with surface warming has been noted) than previous estimates. The result is tropical warming consistent with that found in surface measurements, and consistent with the warming produced by climate models.
- Radiosonde releases provide the longest record of upper-air measurements, and these data exhibit similar warming rates to the surface record since 1958. Unfortunately, vast regions of the oceans and portions of the landmasses (especially in the tropics) are not monitored so that there is always a component of the global or hemispheric mean temperature that is missing. Moreover, measurement errors and sampling issues affect the radiosonde record as well. The correction for non-climatic effects in these records has not received as much attention as for the surface records, but efforts are increasing. A recent study, for instance, finds that after accounting for previously uncorrected errors due to daytime solar heating of the radiosonde instruments, the tropical troposphere has warmed at a rate (0.14° C decade^{-1}) consistent with model simulations and the surface record.

Question 8c. The Hockey Stick. In recent months, there have been assertions that the statistical method used to analyze global temperature data for the last several hundred years was biased towards generating the "hockey stick" shaped curve that shows sustained low and stable temperatures for hundreds of years with an extremely sharp rise in the last 100 years. Can you comment on whether the observations depicted in the hockey stick curve are, indeed, legitimate?

Answer. An important point is that the "hockey stick" curve does not serve as the basis for the scientific consensus that the planet is warming and that this warming is due to human activities. A very large number of independent studies have led to this conclusion.

That said, the results of the original "hockey stick" graph (Mann et al. 1998; *Nature*) are legitimate and remain as a valuable estimate inside the set of available climate reconstructions of past centuries. Not all reconstructions agree in the details, but their primary structure is very similar throughout and they agree with our understanding of possible forcing factors, both natural and anthropogenic.

Without going into detail, the recent criticisms raised against the statistical method used in Mann et al. (1998) either refer to very small effects or they cannot be supported. New investigations into the summaries of North American tree rings show that, independent of the exact procedure used in the summary of the individual series, all methods lead to essentially the same result as the original Mann et al. (1998) reconstruction. Strongly differing results can only be achieved if a significant portion of the climatic signal in the original proxy records is omitted (which, of course, is not desirable). Questions regarding the potential for a very large bias in the century-scale climate amplitude of the Mann et al. (1998) reconstruction (von Storch et al. 2004; *Science*) cannot be reproduced with a code that is verified on the real proxy data. Papers addressing these issues and confirming the validity of the Mann et al. (1998) findings are currently in the peer-review process.

Question 9. Some say that global warming might be a positive development? Will agricultural crop productivity improve due to the greater amount of CO_2 in the atmosphere, and can we expect the Arctic and Antarctic regions to become more habitable?

Answer. Modest amounts of warming will have both positive and negative impacts. The effects of climate change on agricultural productivity depend on numerous inter-related factors, including rising temperatures, increased carbon dioxide in the atmosphere, and average precipitation levels. A modest increase in global temperatures could increase agricultural productivity in some areas by, for instance, lengthening the growing season. As stated earlier, however, the rate of change projected exceeds anything seen in nature in the past 10,000 years and is apt to be disruptive in many ways. For instance, there is likely to be an amplified change in extremes associated with global warming. Extreme events, such as heat waves, floods and droughts, are exceedingly important to both natural systems and human systems and infrastructure.

Concerning high latitude regions, where the warming is expected to be greatest, there is already strong evidence to suggest the current warming is having strong negative impacts. One example is severe coastal erosion due to retreating sea ice, increasing sea level, and thawing of coastal permafrost. Others include negative impacts to buildings, roads, and industry due to thawing of tundra and ice roads. Increases in insect outbreaks and forest fires also accompany ongoing warming. So the evidence is strong that the negative impacts are very likely to outweigh positive ones as rapid warming proceeds.

Question 10. It is my understanding that the assessments of the progression of global warming through the next century and its impacts on changing the Earth's climate are largely based on computer modeling. It goes without saying that the planet's atmospheric, hydrologic, and meteorological systems are highly complicated. What can you say about how climate modeling capabilities have advanced since scientists began evaluating the problem? What is the level confidence that the computer models are providing useful projections of the future climate?

Answer. The best climate models encapsulate the current understanding of the physical processes involved in the climate system, the interactions, and the performance of the system as a whole. They have been extensively tested and evaluated using observations. They are exceedingly useful tools for carrying out numerical climate experiments, but they are not perfect, and some models are better than others. Uncertainties arise from shortcomings in our understanding of climate processes operating in the atmosphere, ocean, land and cryosphere, and how to best represent those processes in models. Yet, in spite of these uncertainties, today's best climate models are now able to reproduce the climate of the past century (Figure 1), and simulations of the evolution of global surface temperature over the past millennium are consistent with paleoclimate reconstructions. This gives increased confidence in future projections.

The shortcomings in our understanding of the processes involved in climate and how they are depicted in models arise from inadequate observations and theoretical underpinnings associated with the incredible complexity of dealing with scales from molecules and cloud droplets to the planetary-scale atmospheric circulation. These issues are addressed in several steps:

- Individual climate processes are dealt with as best as is possible given the understanding and computational limitations.
- The processes are assembled in models and then the model components are tested with strong constraints. The components include modules of the atmosphere, the oceans, the land and sea ice, and the land surface. These modules are coupled together to mimic the real world.
- The climate system model as a whole is then integrated in an unconstrained mode and thoroughly tested against observations.

One strong test is to simulate the annual cycle of seasonal variations (the changes in climate from winter to summer). Another is to simulate observed variability from one year to the next. Yet another is to simulate past climate (Figure 1), even going back in time thousands or millions of years tested against records from ice cores, tree rings, and other "proxy" data.

As our knowledge of the different components of the climate system and their interactions increases, so does the complexity of today's climate models. Also, many of the most pressing scientific questions regarding the climate system and its response to natural and anthropogenic forcings cannot be readily addressed with traditional models of the physical climate. One of the open issues for near-term climate change, for example, is the response of terrestrial ecosystems to increased concentrations of carbon dioxide. Will plants begin releasing carbon dioxide to the atmosphere in a warmer climate, thereby acting as a positive feedback, or will vegetation absorb more carbon dioxide and hence decelerate global warming? Related issues include the interactions among land use change, deforestation by biomass burning, emission of greenhouse gases and aerosols, weathering of rocks, carbon in soils, and marine biogeochemistry.

Exploration of these questions requires a more comprehensive treatment of the integrative Earth system. In order to address these emerging issues, physical models are being extended to include the interactions of climate with biogeochemistry, atmospheric chemistry, ecosystems, glaciers and ice sheets, and anthropogenic environmental change. These new "Earth System Models", however, will require large investments in computing infrastructure before they can be fully utilized.

Question 11. Is the recent rise in global temperature within the scope of natural variation? For instance, it has been observed that the world appears to be on a cyclical temperature pattern of rising and falling into and out of ice ages every several hundred thousand years or so. What has caused global temperatures to vary naturally by 5 to 7 degrees thousands of years ago before humankind started burning fossil fuels and releasing large amounts of carbon dioxide and other greenhouse gases?

Answer. Climate varies naturally. We consider natural variability as resulting from purely internal atmospheric processes as well as from interactions among the different components of the climate system, such as those between the atmosphere and oceans or the atmosphere and land. However, the most significant forcings with impact on climatic time scales are generally imposed upon the climate system.

External forcings arise from a wide array of processes covering a range of spatial and temporal scales. "Natural" external forcings include changes in the global configuration of the continents, the slow increase of solar luminosity that occur over hundreds of millions of years, variations in the Earth's orbit, and the injection of aerosols high into the atmosphere by explosive volcanic eruptions. Human emissions of carbon dioxide and other greenhouse gases, the local emission and suspension of small (aerosol) particles on timescales of minutes to days, and changes in land use are some examples of anthropogenic forcings.

The global temperature variations reflected in ice core records from the distant past reflect the influence of natural external forcings on the climate system. However, these reconstructions of past temperature swings have also demonstrated that the projected rate of global temperature change exceeds anything seen in nature in the past 10,000 years.

Greenhouse gas concentrations in the atmosphere are now higher than at any time in at least the last 750,000 years. It took at least 10,000 years from the end of the last ice age for levels of carbon dioxide to increase 100 ppmv to 280 ppmv, but that same increase has occurred over only the past 150 years to current values of over 370 ppmv. About half of that increase has occurred over the last 35 years, owing mainly to combustion of fossil fuels and deforestation. In the absence of controls, future projections are that the rate of increase in carbon dioxide amount may accelerate, and concentrations could double from pre-industrial values within the next 50 to 100 years.

RESPONSES OF JAMES W. HURRELL TO QUESTIONS FROM SENATOR BUNNING

Question 1. Would you say that the steps America has taken in the recent years to improve energy efficiency and produce lower carbon emissions from power generation are the right first steps in addressing climate change? Within that construct, given the current U.S. electricity supply that is more than 50% derived from coal, is encouraging clean coal technology, IGCC and carbon sequestration the most important immediate policy action we can take?

Answer. The only way to minimize human-induced climate change is to reduce emissions or increase removal of greenhouse gases from the atmosphere. Reducing carbon dioxide emissions from power generation is thus a very important step in addressing climate change. Improving energy efficiency is also desirable.

Regarding the second part of your question, I am not an expert in energy technology, policy or economics. But regarding carbon sequestration, one of the major advances in climate modeling in recent years has been the introduction of coupled climate-carbon models. Climate change is expected to influence the capacities of the land and oceans to act as repositories for anthropogenic carbon dioxide, and hence provide a feedback to climate change. These models now allow us to assess the nature of this feedback.

Results show that carbon sink strengths are inversely related to the rate of fossil fuel emissions, so that carbon storage capacities of the land and oceans decrease and climate warming accelerates with faster carbon dioxide emissions. Furthermore, there is a positive feedback between the carbon and climate systems, so that further warming acts to increase the airborne fraction of anthropogenic carbon dioxide and amplify the climate change.

As a non-expert on energy technology, I can only add that experts believe a portfolio of technologies now exists to meet the world's energy needs over the next 50 years and limit the trajectory of atmospheric carbon dioxide increases. No single element of this portfolio (e.g., nuclear power, efficient baseload coal plants, efficient vehicles, etc.) can do the entire job by itself.

Question 2. Scientific research shows that mitigation actions taken now mainly have benefits 50 years from now. Dr. Hurrell, you said "it is vital that all nations identify cost-effective steps that they can take now." Given that viewpoint, do you agree that clean coal technology, renewable fuels and nuclear power are the most promising areas the government can spend research dollars?

Answer. I cannot suggest which energy technologies should receive greatest emphasis in the near-term because I am not an expert in energy technology or policy. However, as noted above, I believe it is essential to encourage technological innovation and explore the entire spectrum of energy generating technologies, including nuclear, clean coal, and renewable fuels.

Question 3. While you have presented what appears to be a united scientific front in the form of the statement from the academies of science from 11 countries, I am concerned by some of the news since the release of that statement. The Russian Academy of Sciences says it was misrepresented and that Russian scientists actually believe that the Kyoto Protocol was scientifically ungrounded. I am also aware that there was a significant misrepresentation on the science between our academy and the British representative. Given this background, wouldn't you say there are still some pretty fundamental disagreements about the science of climate change among scientists around the world?

Answer. As outlined in my written testimony, I do not believe there are fundamental disagreements about the science of climate change. Please also see my response to *Question 3* from Senator Bingaman. There is overwhelming agreement among climate scientists that human activities are increasing the concentrations of greenhouse gases in the atmosphere and that this is resulting in significant changes to Earth's climate.

I therefore believe the academies statement accurately represents the current state of scientific understanding of climate change. However, I was not involved in the process of generating the statement, and I respectfully suggest that further concerns are most appropriately addressed to representatives of the U.S. National Academy.

Question 4. In this international academies statement, you find that an "immediate response that will, at a reasonable cost, prevent dangerous anthropogenic interference with the climate system," but continue to say in the following paragraph, "minimizing the amount of this carbon dioxide reaching the atmosphere presents a huge challenge." Could you please elaborate, since any response can't both be a "reasonable cost" and a "huge challenge" proposition, how you resolve the two?

Answer. Again, I respectfully suggest that questions about the international academies statement are most appropriately addressed to those who drafted and issued the statement. I would point out that the challenge of dealing with climate change involves much more than financial costs. One aspect of this challenge is the very long-term nature of climate change. The emissions of greenhouse gases that have already occurred will result in climate changes that play out for decades, or, in the case of sea-level rise, over centuries. We will thus need to devise and maintain multi-generational mitigation and adaptation strategies. I believe that this can be properly characterized as a huge challenge quite apart from the issue of financial costs.

Question 5. Several scientists have cited events like the high temperatures in Europe in the summer of 2003 and increased storminess in the 1980s and 1990s as evidence of climate change. Don't global ecosystems go through natural periods similar to these as well?

Answer. Climate varies naturally from both internal processes and from changes in "natural" external forcing (see my response to *Question 11* from Senator Bingaman). However, the critical point is that the projected rate of global temperature change exceeds anything seen in nature in the past 10,000 years, and it is unlikely many natural systems can adapt. An example is the coral reefs, which some scientists believe are already beyond a point of recovery as a result of ocean warming. Greenhouse gas concentrations in the atmosphere are now higher than at any time in at least the last 750,000 years, with very rapid increases in recent decades owing to mainly the combustion of fossil fuels and deforestation. In the absence of controls, future projections are that the rate of increase in carbon dioxide amount may accelerate, and concentrations could double from pre-industrial values within the next 50 to 100 years. Thus, we will experience climate conditions in the next 100 years that are very different from any experienced during the entire development of human society.

Question 6. There are a number of astrophysicists and other scientists who believe that sunspots are a major contributor to changing temperatures. A recent survey showed at least 100 such studies are underway. Why don't scientists put as much emphasis on this possibility or other aspects of natural climate variability as they do on emissions from human activity?

Answer. Scientists put a tremendous effort on unraveling the complexities of the climate system, including the role that changes in natural external forcings (such as changes in solar luminosity) have played in producing past variations in global surface temperature. Our understanding of the physical processes involved in the climate system is encapsulated in today's climate system models, which are now able to reproduce the climate of the past century with impressive fidelity (see Figure 1 and my response to *Question 1* from Senator Bingaman). As a result, climate modelers are able to test the role of various forcings in producing the observed changes in global temperature. These simulations clearly indicate that the global surface warming of recent decades is a response to the increased concentrations of greenhouse gases and sulfate aerosols in the atmosphere. When the models are run without these forcing changes, and only include "natural" forcings from changes in solar irradiance and volcanic eruptions, they fail to capture the almost linear increase in global surface temperatures since the mid-1970s.

Question 7. Much of the discussion about climate science being settled is based on the summary chapter of the Intergovernmental Panel on Climate Change of the United Nations. The chapter made specific predictions about the pace of rising temperatures and the relative importance of human activities to climate change. And yet, the body of the report is much more ambiguous and inconclusive about the current state of the science. Is anything being done to ensure that the summary of the next IPCC report is more reflective of the overall analysis by the scientists?

Answer. I assume the question is referring to the Summary for Policy Makers (SPM), which is approved word-by-word and line-by-line in an Intergovernmental Meeting in which the U.S. Government fully participates. This summary involves negotiations about how the scientific findings are expressed, but it does not change the science on which it is based. There is also a Technical summary and executive summaries for each chapter. The report as a whole goes through a very rigorous review process (see my response to *Question 3* from Senator Bingaman and also my written testimony for more details on the IPCC process). The openness of the entire process results in a very credible, consensus document.

Question 8. The natural "greenhouse effect" has been known for nearly two hundred years and is essential to the provision of our current climate. There is significant research in the literature today that indicates humans, since the beginning of their existence, have caused an increase in the greenhouse effect. Some argue that the development of agriculture 6,000 to 8,000 years ago has helped to forestall the next ice age. The development of cities, thinning of forests, population growth, and most recently the burning of fossil fuels, have all had an impact on climate change. Our ecosystems have constantly adapted to change, as we as humans have adapted to our ecosystems as well. Is it possible that the increased presence of CO_2 caused by the 8,000 years of modern human existence may be something our ecosystems will continue, as they previously have, to naturally adapt to?

Answer. Ecosystems do not adapt to change. Individual species that make up ecosystems adapt to changing climate conditions, move, or go extinct. Ecosystems change as the mixture and characteristics of species within them change. In some cases, ecosystems disappear and are replaced by other ecosystems that contain different species and provide different services.

It is true that a broad range of human activities, including land use change, thinning or removal of forests, and, more recently, the use of fossil fuels, have affected the Earth's climate and ecosystems over the course of human history. But we are witnessing a unique period.

Greenhouse gas concentrations in the atmosphere are now higher than at any time in at least the last 750,000 years. It took at least 10,000 years from the end of the last ice age for levels of carbon dioxide to increase 100 ppmv to 280 ppmv, but that same increase has occurred over only the past 150 years to current values of over 370 ppmv. About half of that increase has occurred over the last 35 years, owing mainly to combustion of fossil fuels and deforestation. In the absence of controls, future projections are that the rate of increase in carbon dioxide amount may accelerate, and concentrations could double from pre-industrial values within the next 50 to 100 years. The result is that the rate of change as projected exceeds anything seen in nature in the past 10,000 years.

The rapid climate change that we are experiencing now is already affecting some ecosystems. The ranges of migrating birds and some fish and insect species are changing. Tropical regions are losing animal species, especially amphibians, to warming and drying, and coral reefs are dying because of excess ocean warmth. Continued rapid climate change is expected to result in significant ecosystem impacts over the next 100 years and beyond. Some plants and animals may be unable to adapt or migrate in response to such a rapidly changing climate. Rare ecosystems, like mangrove forests and alpine meadows, could disappear in some areas.

RESPONSES OF JAMES W. HURRELL TO QUESTIONS FROM SENATOR TALENT

Question 1. You note that most of the warming since 1979 has occurred in cold-weather winter and spring months, and that only 0.7 degree Centigrade. Is there any harm in this?

Answer.The warming has occurred in all seasons and over much of the globe, but not uniformly. Climate models used to project future climate indicate that the largest temperature increases will occur over land relative to oceans, with the greatest warming at high latitudes of the Northern Hemisphere during the winter and spring seasons—much like the pattern we are observing. Over portions of North America, Europe and Asia regional increases in average surface temperature since 1979 have exceeded 1-2° C (see Figure 2 in my response to Senator Bingaman).

Modest warming will have both positive and negative impacts. A modest increase in global temperatures could increase agricultural productivity in some areas by, for instance, lengthening the growing season. But in high latitude regions, where the warming is expected to be greatest, there is already strong evidence to suggest the current warming is having strong negative impacts, such as severe coastal erosion due to retreating sea ice, increasing sea level, and thawing of coastal permafrost. The thawing of tundra is having negative impacts on buildings, roads, and industry. Higher global sea levels associated with warmer ocean temperatures mean that storm surges associated with hurricanes will be more destructive. Moreover, the rate of future warming as projected exceeds anything seen in nature in the past 10,000 years.

Question 2. You also note that temperatures from 1861-1920 were constant, with a 0.3 degree Centigrade warming from 1921-1950, a cooling of 0.1 degree through the mid 1970s, followed by a warming of 0.55 degree through now. Doesn't this imply temperature fluctuation more so than the usual argument of a constant increase in temperature? If nothing else, doesn't it imply that nature causes of temperature change more than overtake those of human origin (since emissions have generally been increasing throughout the Industrial Age and didn't drop off in the 50s, 60s, and 70s)?

Answer. Global average surface temperatures show a linear warming trend of 0.6° C ±0.2° C since the beginning of the 20th century. Linear trends are a simple way to summarize the change in a time series over some period of time. In my written testimony, I was noting that the change in observed global surface temperatures is more complex than a simple linear trend value would indicate (see Figure 1 in my response to Senator Bingaman).

You are correct to note that natural variations are evident in the global surface temperature record. Natural variations result from purely internal atmospheric processes as well as from interactions among the different components of the climate system, such as those between the atmosphere and ocean associated with the El Niño/Southern Oscillation (ENSO) phenomenon in the tropical Pacific. Changes in solar luminosity and the injection of aerosols high into the atmosphere by explosive volcanic eruptions are also considered to be "natural" external forcings. Many of the large amplitude year-to-year fluctuations evident in Figure 1 reflect ENSO, volcanic eruptions and other variations associated with natural variability. Natural variations also affect temperatures on longer time scales, for instance associated with multi-decadal variations in the Meridional Overturning Circulation (MOC) in the ocean.

Climate models, when forced with known changes in natural external forcings, produce variations in global surface temperatures that mimic observations; yet, these simulations fail to reproduce the observed warming over recent decades (Figure 1). The recent warming (which, incidentally, is well described by a linear trend) can only be captured when known changes in anthropogenic forcings are added to the models as well. This result, combined with many other pieces of knowledge (summarized in my written testimony), led the IPCC to conclude in its third assessment report that "*most of the warming observed over the last 50 years is attributable to human activities*." The best assessment of global warming remains that the human climate signal emerged from the noise of background variability in the late 1970s.

Question 3. You add that the National Research Council in 2000 studied the problem and concluded that "the warming trend in global-mean surface temperature observations during the past 20 years is undoubtedly real and is substantially greater than the average rate of warming during the 20th century. The disparity between surface and upper air trends in no way invalidates the conclusion that surface temperature has been rising." Please explain the basis for the strong NRC position in the face of remaining data discrepancies.

Answer. Please see both my written testimony and my answer to *Question 8* from Senator Bingaman for more relevant details. In short, *initial* analyses of satellite data that measure the temperature of broad atmospheric layers indicated that temperatures in the troposphere showed little or no warming, in stark contrast with surface air measurements. Climate change skeptics used this result to raise questions about the reliability of the surface record. The NRC report, however, did not find this to be the case. It, like the IPCC assessments and many independent studies in the refereed literature, concluded that, while the surface record is not perfect, it does depict large-scale changes in surface temperature to a high level of certainty.

Independent analyses of global upper-air temperatures derived from satellites also show warming since 1979, when the satellite record begins. However, trend estimates range from 0.04 to 0.17° C decade^{-1}. Such differences highlight the issue of temporal homogeneity in the satellite data.

Question 4. You note that even if we would have stabilized our emissions as of 2000, temperatures would still increase by 0.5 degree C by 2100. What level of emissions reductions would be needed (and when) in the U.S. and world-wide to accomplish this? If developing nations do not participate (as we expect they won't) and in fact increase their emissions (as we expect they will), what greater level of reductions would the U.S. have to make?

Answer. The first part of your question refers to the so-called "commitment" runs performed by several modeling groups around the world in order to examine the climate response if there are no further increases in global emissions of greenhouse gases into the atmosphere. So, effectively, no additional reductions are required for this emission scenario to be realized. However, as you note, further increases in emissions are likely, especially as countries like China and India strive to reach a standard of living similar to ours.

The second question is beyond my expertise. I do note, however, the CO_2 emissions reductions necessary to achieve a given target depend on the quantitative details of the stabilization target, the emissions judged likely to occur in the absence of a focus on carbon (a business-as-usual trajectory), and how natural sinks for atmospheric CO_2 will behave (see also my response to *Question 1* from Senator Bunning). For reference, Pacala and Socolow (2004, *Science*) note that stabilization at 500 ppmv (the current CO_2 concentration is near 375 ppmv) requires that emissions be held near current levels (7 GtC year^{-1}) for the next 50 years, even though they are currently on a doubling path. This is because greenhouse gases have very long atmospheric lifetimes. They build up in amounts over time, as has been observed.

Question 5. You note that the benefits of actions taken today won't appear for 50 years or more. Can you even quantify those benefits, or offer any degree of certainty that they will be realized? Will they even materialize unless we take the drastic action of reducing emissions to 2000 levels (or lower)?

Answer. I note in my written testimony that "it should be recognized that mitigation actions taken now mainly have benefits 50 years and beyond now." Again, this statement refers to the long lifetime of CO_2 in the atmosphere and the slow equilibration of the oceans, so that there is a substantial future commitment to further global climate change even in the absence of further emissions of greenhouse gases into the atmosphere. The consequence of inaction is that the rate of increase in carbon dioxide amount may accelerate, and concentrations could double from pre-industrial values within the next 50 to 100 years. The resulting very rapid rate of climate change is apt to be disruptive in many ways, as summarized by the IPCC and elsewhere.

Question 6. If all the countries that have signed Kyoto stay within compliance of Kyoto, how much of a reduction in global warming would this result in?

Answer. If the Kyoto Protocol had gone into effect with the U.S. included, studies indicate that, under reasonable assumptions, it would delay the doubling of carbon dioxide concentrations in the atmosphere by about 15 years (from about 2060 to 2075). This result, however, depends greatly on what is done after 2012. Without U.S. involvement, the gain is closer to 10 years.

Question 7. Can you confirm that suspended water vapor levels, cloud cover percentages and direct solar irradiation changes over time all represent variables in these forecasting models that could have significant impacts on the conclusions of the results of these models?

Answer. The best climate models encapsulate the current understanding of the physical processes involved in the climate system, the interactions, and the performance of the system as a whole. They have been extensively tested and evaluated using observations. They are exceedingly useful tools for carrying out numerical climate experiments, but they are not perfect, and some models are better than others.

Water vapor, cloud, and solar radiation are all dealt with in climate models, although there is considerable uncertainty associated with the depiction of cloud owing to its complexity. In fact, this is a major source of the uncertainty in future climate projections, and it is fully expressed in the projections of IPCC. In spite of differences among models and the uncertainties that exist, however, climate models produce some consistent results regarding future projections of climate, as detailed in my written testimony. For instance, regardless of the emissions scenario, all climate models produce very similar warming trends over the next few decades.

Question 8. In looking at pre-industrial global temperature patterns, would you agree that changes in temperatures over time have occurred that had no anthropogenic basis?

Answer. Yes. And this is true of today's climate as well. Please see my answer to your *Question 2.*

Question 9. Do we know what the "best" global temperature is to sustain life?

Answer. It seems to me that the answer to this question will vary depending on the nature of life, whether biota, insects, mammals, or humans. The process of evolution guarantees that we are most adapted to the current or past climate. Life itself depends enormously on intricate webs and predator-prey relationships, so that if one link in the chain is upset it can propagate through the whole chain. Examples abound. These include how earlier springs lead to earlier hatching of insects but perhaps not birds. So, when the birds hatch, their traditional food is no longer available and they may be in jeopardy. This also happens with disruptions like drought. Drought dries up puddles and lakes and destroys the natural predators for mosquito larvae, so after a drought there is an expansion of mosquitoes and greater risk of outbreaks of vector borne disease such as malaria or Rift Valley fever.

Question 10. What is currently being done to curb emissions from parts of the world in poverty who are deforesting their environment and burning biomass for all means of day-to-day living, and are these emissions continuing to increase in the world?

Answer. I am not a policy expert, and I am not familiar with the policies of other nations. I cannot answer this question, beyond noting that deforestation and biomass burning is accelerating in many parts of the world.

Question 11. Do you believe it is practical to seek emission controls in parts of the world that are struggling in poverty?

Answer. My personal view it that it is vital that all nations identify cost-effective steps that they can take now, to contribute to substantial and long-term reductions in net global greenhouse gas emissions. Some countries can do more than others, but it is important that the science not be ignored while designing policies.

Question 12. What is being done to curb emissions in the developing countries like China and India?

Answer. Again, I am not a policy expert. I am unfamiliar with what is being done in countries like China and India to curb emissions, but I hope they are considering the diverse portfolio of energy technologies that exists now and can contribute toward stabilization strategies.

Responses of James W. Hurrell to Questions From Senator Feinstein

Question 1. Is there any credible scenario for stabilizing greenhouse gas emissions that does not involve the United States and other major emitters stopping their emissions growth over the next couple of decades and sharply reversing their emissions growth by 2050?

Answer. The answer depends on the stabilization target as well as several other factors. Pacala and Socolow (2004, *Science*) note that stabilizing atmospheric concentrations of CO_2 at 500 ppmv (the current CO_2 concentration is near 375 ppmv) requires that global emissions be held near current levels (7 GtC year^{-1}) for the next 50 years, even though they are currently on a doubling path. Holding global emissions near current levels for the next 50 years would require that emissions growth in any particular nation or group of nations be matched by emissions reductions elsewhere. Such an effort requires full consideration of the diverse portfolio of energy technologies that exists.

Question 2. Would the National Commission on Energy Policy's proposal stop and then reverse U.S. greenhouse gas emissions?

Answer. I am not familiar with the proposal you reference. I cannot comment.

Responses of Ralph J. Cicerone to Questions From Senator Bingaman

Question 1. Over the last several decades, anthropogenic emissions have "substantially contributed" to the increase in average global temperatures. Upon receiving a question from one of the Senators, one of the panelists suggested that "80 percent" of the warming was due to human activities. Do all the panelists agree? Please provide information as to how this estimate was derived.

Answer. I am not sure of the 80 percent number specifically, but I do agree that it is likely that most of the global mean surface temperature increase since the late 1970s is due to human activities. This conclusion is consistent with that reached by Intergovernmental Panel on Climate Change (IPCC) in their 2001 assessment of the scientific literature and the 2001 report of the NRC *Climate Change Science: An Analysis of Some Key Questions.*

This conclusion is generally based on studies that compare the observed climate record from 1860 to today with global mean temperature simulated in three computational climate model scenarios:

1) Only natural variability (due to solar and volcanic variability)
2) Only anthropogenic variability (due to greenhouse gases and aerosols)
3) Both natural and anthropogenic variability

In these studies, the models run with only natural variability are unable to reproduce the warming observed since the late 1970s, typically showing no trend over this time period (e.g., Stott et al., 2000; Meehl et al., 2004). Thus, we conclude that human-caused climate forcings have disrupted Earth's energy balance, causing an increase in global mean surface temperatures (NRC, 2005).

Improved understanding of the natural variability of the climate system supports the conclusion that human activities are mostly responsible for global temperature increases of the past three decades. In particular, new studies of solar variability show that there has been little if any trend in the Sun's brightness over the past 25 years, ruling out solar variability as a major driver of observed warming (see Response to #7 for more details).

Because of the still uncertain level of natural variability inherent in the climate record and the uncertainties in the time histories of the various forcing agents, a causal linkage between the buildup of greenhouse gases in the atmosphere and the observed climate changes during the 20th century cannot be unequivocally established. The fact that the magnitude of the observed warming is large in comparison to natural variability as simulated in climate models is suggestive of such a linkage, but it does not constitute incontrovertible proof of one because the model simulations could be deficient in natural variability on the decadal to century time scale.

Question 2. We received testimony that sought to distinguish between average global temperature changes causes primarily by anthropogenic emissions and local/regional temperature changes caused at times by natural variation. Please explain in greater detail.

Answer. As discussed in the response to #1, there is good evidence that anthropogenic emissions of greenhouse gases are responsible for global mean increases in surface temperature that have been occurring since the late 1970s. It is more difficult to attribute changes observed on local and regional scales to anthropogenic causes because the range of natural climate variability is known to be quite large (in excess of several degrees Celsius) on these smaller spatial scales and shorter time scales and because global climate models have more skill in predicting climate for large regions and long time scales. 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.

Question 3. Please explain the meaning of 'scientific consensus' and comment on the status of the science of climate change in the scientific and academic community.

Answer. Scientific understanding is continually undergoing changes and refinements as hypotheses are tested and experiments are conducted. At any one time it is possible in various ways to test the degree of consensus that may exist about the state of scientific knowledge in a particular area and the degree of uncertainty that may exist. For example, the National Research Council has developed a process to produce its "consensus" reports regarding current scientific knowledge. The NRC process begins by selecting a committee of highly-qualified experts that represents the range of disciplines, expertise, and perspectives necessary to make an informed and objective assessment on the topic in question. The committee assembles data from a variety of sources, including the scientific literature, the testimony of other experts, and the public. Using these data, its own collective knowledge, and assessment of the existing scientific evidence, the committee conducts deliberations and writes a draft report of consensus findings with supporting arguments. Each committee member must agree to all of the findings and recommendations in the report, although in rare cases a committee member can ask that a dissenting opinion be included. Each report is subjected to rigorous, anonymous review by a group of independent experts before it is approved in final form and released to the public. The National Research Council has issued a number of reports concerning the state of knowledge and uncertainties in climate change science.

The climate science community has also developed additional processes for articulating consensus on the state of science, largely through the preparation of assessment reports. The largest and most well-known of climate assessment activities is conducted by the Intergovernmental Panel on Climate Change (IPCC), which has produced major assessments on a regular basis over the past 15 years. The most recent IPCC assessment of the science of climate change was published in 2001 (IPCC, 2001). An NRC committee examined this assessment and found that the full IPCC Working Group I report is an admirable summary of research activities in climate science (NRC, 2001a). IPCC (2001) and NRC (2001a) both conclude that climate is changing and that the recent changes are likely due in large part to human activities.

A less formal way of identifying a scientific consensus is by considering the breadth of the scientific literature and presentations at scientific conferences. For example, a recent analysis of over 900 papers published in refereed scientific journals between 1993 and 2003 with keywords "global climate change" concluded that there is a strong convergence of views in the scientific community that climate is changing and that recent warming is largely due to human activities (Oreskes, 2004).

Question 4. What is "abrupt climate change"? Can you identify any potential thresholds that might be crossed if insufficient action is taken to control CO_2 emissions? For example, I have heard that beyond certain temperature increases, large ice sheets could collapse, leading to huge increases in sea level. Can you comment on this and other potential thresholds?

Answer. Abrupt climate change generally refers to a large shift in climate that takes place so rapidly and unexpectedly that human or natural systems have difficulty adapting to it. Such a climate shift can persist for years or longer—such as marked changes in average temperature, or altered patterns of storms, floods, or droughts—over a widespread area such as an entire country or continent, In the context of past abrupt climate change, "rapidly" typically means on the order of a decade (NRC, 2002).

Abrupt climate change can occur when the Earth system gets pushed across a threshold, whether by some sudden event like a massive volcanic eruption or by the accumulation of more gradual changes in the climate system. It is not yet known what the thresholds are or whether human-induced increases in greenhouse gases will trigger abrupt climate changes. Scientists are concerned about increasing greenhouse gases because past abrupt climate changes have been especially common when the climate system itself was being altered.

A question of great societal relevance is whether the North Atlantic circulation, including the Gulf Stream, will remain stable under the global warming that is expected to continue for the next few centuries. A shutdown of the circulation would not induce a new ice age, but would cause major changes both in the ocean (major circulation regimes, upwelling and sinking regions, distribution of seasonal sea ice, ecological systems, and sea level) and in the atmosphere (land-sea temperature contrast, and the intensity, frequency, and paths of storms).

Other potential impacts of a global-warming induced abrupt climate change could be associated with increased frequency of extreme events related to land-surface hydrology. Great variability in precipitation patterns, ranging from heavy rainstorms and flooding to persistent drought, might become more common. In particular, some models suggest that greenhouse warming will cause El Niño manifestations to become stronger and more frequent. It is important to note that not all models agree on the potential impacts of global warming on abrupt climate change.

Question 5. Can you tell us something about the time horizon for stabilizing climate, given how long carbon dioxide remains in the atmosphere? Do we need to begin to control emissions now or can we wait?

Answer. Carbon dioxide can remain in the atmosphere for many decades and major parts of the climate system respond slowly to changes in greenhouse gas concentrations. Although carbon dioxide is the most significant greenhouse gas perturbed by humans, other anthropogenic greenhouse gases also have an important impact on climate. These include (1) methane, for which concentrations have increased by about a factor of 2.5 since preindustrial times, but have stopped increasing more recently for unknown reasons; (2) halocarbons such as chlorofluorocarbons, whose emissions were controlled because they contribute to ozone depletion in the stratosphere; and (3) nitrous oxide, which continues to rise.

Even if greenhouse gas levels were stabilized instantly at today's levels, the climate would still continue to change as it adapts to the increased emissions of recent decades, as illustrated in Figure 1. For current models with a midrange climate sensitivity and average assumptions about the greenhouse effects of atmospheric aerosols, Wigley (2005) estimates next 400 years, with most of the warming occurring within the first 100 years (see the center red line in Figure 1*). Thus, even with no greenhouse gas emissions from this point forward, we would be experiencing the impacts of climate change throughout the 21st century and beyond.

If it were possible to control emissions such that they stayed at today's levels into the future, we would not be able to stabilize climate for at least 400 years, as illustrated in Figure 2. Failure to implement significant reductions in net greenhouse gas emissions now, will make the job much harder in the future.

Question 6. Given that there is still some uncertainty about the details of future warming, how should such uncertainty be dealt with in designing policy responses?

Answer. Pinpointing the magnitude of future warming is hindered both by remaining gaps in understanding the science and by the fact that it is difficult to predict society's future actions, particularly in the areas of population growth, economic growth, and energy use practices. However, a lack of full scientific certainty about some aspects of climate change is not a reason for delaying an immediate response that will, at a reasonable cost, prevent dangerous anthropogenic interference with the climate system. Indeed, relevant policy actions that affect population growth, economic growth, energy use practices, and other societal factors will have an impact on future warming.

Question 7. How do we know that emissions of carbon dioxide and other greenhouse gases are causing Earth's temperature to rise, as opposed to other factors that we have no control over; such as sun spots? Some assert that an increase in solar irradiance is the main cause of the Earth's current warming trend. Therefore, reducing fossil fuel emissions would not impact the Earth's temperature.

Answer. Please see the response to #1, which addresses how scientists attempt to determine the contributions of natural and human causes to observed climate change.

The extent to which variations in the Sun might contribute to recent observed warming trends is an area of active research. The Sun's brightness—its total irradiance—has been measured continuously by a series of satellite-based instruments for more than two complete 11-year solar cycles. These multiple solar irradiance datasets have been combined into a composite time series of daily total solar irradiance from 1979 to the present. Different assumptions about radiometer performance lead to different reconstructions for the past two decades. Recent analyses of these measurements, taking into account instrument calibration offsets and drifts, argue against any detectable long-term trend in the observed irradiance to date. Likewise, models of total solar irradiance variability that account for the influences of solar activity features—dark sunspots and bright faculae—do not predict a secular change in the past two decades. Thus, it is difficult to conclude from either measurements or models that the Sun has been responsible for the warming observed over the past 25 years, although this hypothesis was more plausible before the availability of more recent evidence.

Knowledge of solar irradiance variations prior to the commencement of continuous space-based irradiance observations in 1979 is rudimentary. Models of sunspot and facular influences developed from the contemporary database have been used to extrapolate daily variations during the 11-year cycle back to about 1950 using contemporary sunspot and facular proxies, and with less certainty annually to 1610. Circumstantial evidence from cosmogenic isotope proxies of solar activity (^{14}C and ^{10}Be) and plausible variations in Sun-like stars motivated an assumption of long-term secular irradiance trends, but recent work questions the evidence from both (Lean et al., 2002). Very recent studies of the long term evolution and transport of activity features using solar models suggest that secular solar irradiance variations may be limited in amplitude to about half the amplitude of the 11-year cycle.

Question 8. There are some who question the veracity of the assertion that the earth has warmed substantially over the last century. Arguments typically fall into three categories. It would be useful if you would address each in turn:

a. *Urban Heat Island Effect*. This is the claim that the underlying temperature data is tainted by the proximity of data-generating thermometers to cities. As urban areas have grown over the last fifty years, the air temperatures around these cities

*Figures 1-3 have been retained in committee files.

have increased due to larger amounts of heat generating substances like rooftops and roadways. Scientists claim to have corrected for the urban heat island effect.

b. *Satellite and Airborne Balloon Data Contradict Surface Temperature Readings*. Global mean temperature at the earth's surface is estimated to have risen by about half a degree F over the last two decades. On the other hand, satellite measurements of radiances and airborne balloon observations indicate that the temperature of the lower to mid-troposphere (the atmospheric layer extending from the earth's surface up to about 8 km) has exhibited almost no change during this period.

c. *The Hockey Stick*. In recent months, there have been assertions that the statistical method used to analyze global temperature data for the last several hundred years was biased towards generating the "hockey stick" shaped curve that shows sustained low and stable temperatures for hundreds of years with an extremely sharp rise in the last 100 years.

Question 8a. Urban Heat Island Effect. How was this done, and how can we be sure that it was done correctly?

Answer. The possibility of extra heating associated with cities biasing the global mean temperature records is a legitimate concern, which scientists have researched over the past decade. The conclusion of this research is that estimates of long-term global land-surface air temperature trends are relatively little affected by whether or not the averaging includes urban stations. Urban effects on globally averaged land surface air temperatures do not exceed about 0.05° C over the period 1900 to 1990, compared to an overall trend of about 0.7° C. This conclusion has been reached by comparing the trend at urban stations to that at rural stations (e.g., Peterson et al., 1999).

Question 8b. Satellite and Airborne Balloon Data Contradict Surface Temperature Readings. Please explain whether this discrepancy is, indeed, real and how to account for it.

Answer. A National Academies report released in 2000, *Reconciling Observations of Global Temperature Change*, examined different types of temperature measurements collected from 1979 to 1999 and concluded that the warming trend in global-average surface temperature observations during the previous 20 years is undoubtedly real and is substantially greater than the average rate of warming during the 20th century. The report concludes that the lower atmosphere 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 report spurred many research groups to do similar analyses. Satellite observations of middle troposphere temperatures, after several revisions of the data, now compare reasonably with observations from surface stations and radiosondes, although some uncertainties remain.

Question 8c. The Hockey Stick. Can you comment on whether the observations depicted in the hockey stick curve are, indeed, legitimate?

Answer. Observations of global mean surface temperature of the past 1000 years do show a rapid increase in the last 100 years, with particularly significant warming in the last 30 years. This result has been demonstrated by many different groups of scientists using different assumptions and methodologies (see Figure 3).

Question 9. Some say that global warming might be a positive development? Will agricultural crop productivity improve due to the greater amount of CO_2 in the atmosphere, and can we expect the Arctic and Antarctic regions to become more habitable?

Answer. There will be winners and losers from the impacts of climate change, even within a single region, but globally the losses are expected to outweigh the benefits. Some impacts include:

- Some regions will have increased agricultural productivity due to longer growing seasons, fertilization by higher levels of atmospheric CO_2, or changing precipitation patterns, and there may be an overall increase in timber productivity. However, other areas, particularly arid and semi-arid regions, will have decreased agricultural productivity due to likely decrease in available soil moisture.
- Temperate and arctic regions will have decreased energy demands for winter-time heating, although this brings the negative impact of increased energy demands for summer-time cooling.
- Melting of sea-ice in the Arctic could open up new shipping lanes and ecotourism opportunities.
- Melting of the permafrost in the Arctic will compromise infrastructure (e.g., roads and buildings) built on those lands.

- There will likely be shifts in plant and animal habitats, both terrestrial and oceanic, in the Arctic. This could benefit some aspects of life in the Arctic, but indigenous populations who have traditional lifestyles will likely have difficulty adapting quickly to the changes.
- The changes in Antarctica are anticipated to take place more slowly, so it is difficult to say whether the continent will become more habitable anytime soon.

Question 10. It is my understanding that the assessments of the progression of global warming through the next century and its impacts on changing the Earth's climate are largely based on computer modeling. It goes without saying that the planet's atmospheric, hydrologic, and meteorological systems are highly complicated. What can you say about how climate modeling capabilities have advanced since scientists began evaluating the problem? What is the level confidence that the computer models are providing useful projections of the future climate?

Answer. Climate system models are an important tool for interpreting observations and assessing hypothetical futures. They are mathematical computer-based expressions of the thermodynamics, fluid motions, chemical reactions, and radiative transfer of Earth climate that are as comprehensive as allowed by computational feasibility and by scientific understanding of their formulation. Their purpose is to calculate the evolving state of the global atmosphere, ocean, land surface, and sea ice in response to external forcings of both natural causes (such as solar and volcanic) and human causes (such as emissions and land uses), given geography and initial material compositions. Such models have been in use for several decades. They are continually improved to increase their comprehensiveness with respect to spatial resolution, temporal duration, biogeochemical complexity, and representation of important effects of processes that cannot practically be calculated on the global scale (such as clouds and turbulent mixing). Formulating, constructing, and using such models and analyzing, assessing, and interpreting their answers make climate system models large and expensive enterprises. The rapid increase over recent decades in available computational speed and power offers opportunities for more elaborate, more realistic models, but requires regular upgrading of the basic computers to avoid obsolescence. Their simulation skill is limited by uncertainties in their formulation, the limited size of their calculations, and the difficulty of interpreting their answers that exhibit almost as much complexity as in nature (NRC, 2001b). Even though some scientists might prefer a simpler way to project future climate, these models are currently the best option because they are the only tool that can incorporate the relevant information about the climate system.

The National Academies' report *Improving the Effectiveness of U.S. Climate Modeling* (2001b) offers several recommendations for strengthening climate modeling capabilities, some of which have already been adopted in the United States. At the time the report was published, U.S. modeling capabilities were lagging behind some other countries. The report identified a shortfall in computing facilities and highly skilled technical workers devoted to climate modeling. Federal agencies have begun to centralize their support for climate modeling efforts at the National Center for Atmospheric Research and the Geophysical Fluid Dynamics Laboratory. However, the U.S. could still improve the amount of resources it puts toward climate modeling as recommended in *Planning Climate and Global Change Research* (2003).

Question 11. The 2001 NAS review of climate-change science that you chaired has been interpreted by some as reinforcing the view that human-caused climate change is a real and urgent problem, while others say it reinforces the view that the uncertainties are so large that no action should be taken until they are reduced.

a. Which group is right?

b. If you were rewriting your report today, some four years later, how would it be different?

Answer. NRC (2001a) describes the state of science on climate change and does not address policy choices. In the intervening years, new research has addressed some of the uncertainties identified in NRC (2001a). In my opinion, if NRC (2001a) were written today, it would give greater emphasis to at least four new findings:

- *Longer and more compelling temperature record:*

  The years 2001-2004 are four of the five hottest since the late 1880s for global mean surface temperature (1998 was the hottest).
- *Better Understanding of Surface and Atmospheric Temperature Trends*

  Discrepancies among temperature measurements taken by instruments on the surface of the Earth, on balloon-borne radiosondes, and on satellite platforms engendered debate about the warming trend. In recent years, corrections to each of the data sets (e.g., Sherwood et al., 2005; Mears and Wentz, 2005) along with improved understanding of atmospheric dynamics have made it possible to eliminate the differences or else explain them based on the physical understanding of the system. All three data sets now have a significant warming trend at the surface.

- *Ocean Heat Content Changes Consistent with Greenhouse Warming:*
  The ocean, which represents the largest reservoir of heat in the climate system, has warmed by about 0.12° F (0.06° C) averaged over the layer extending from the surface down to 750 feet, since 1993. Recent studies have shown that the observed heat storage in the oceans is consistent with expected impacts of a human-enhanced greenhouse effect (Hansen et al., 2005).
- *Solar Variability too Small to Explain Warming:*
  One area of debate has been the extent to which variations in the Sun might contribute to recent observed warming trends. The Sun's total brightness has been measured by a series of satellite-based instruments for more than two complete 11-year solar cycles. Recent analyses of these measurements argue against any detectable long-term trend in the observed brightness to date. Thus, it is difficult to conclude that the Sun has been responsible for the warming observed over the past 25 years.

RESPONSES OF RALPH J. CICERONE TO QUESTIONS FROM SENATOR BUNNING

Question 1. Would you say that the steps America has taken in the recent years to improve energy efficiency and produce lower carbon emissions from power generation are the right first steps in addressing climate change? Within that construct, given the current U.S. electricity supply that is more than 50% derived from coal, is encouraging clean coal technology, IGCC and carbon sequestration the most important immediate policy action we can take?

Answer. Over the last several years, there have been dramatic improvements in energy efficiency for most electricity using technologies. For example, according to the National Academies' study, *Energy Research at DOE: Was It Worth It?*, the sales-weighted average electricity use by refrigerators sold in the United States dropped from about 1365 kWh/year in 1979 to about 600 kWh/year in 2001.[1] The record for other electric appliances and air conditioning has also been similar. Of course, there has also been a significant growth in the number of such appliances installed over the same period due primarily to the growth in the number of households. Coupled with increases in the average size of a residence and in the number of electricity-using devices per household, there has been continued growth in the demand for electricity over the same period. According to the Energy Information Administration total electricity use in the residential sector has increased from 683 billion kWh in 1979 to 1203 billion kWh in 2001. Similar behavior has been observed in the commercial sector where electricity use has grown from 473 billion kWh in 1979 to 1080 billion kWh in 2001. The rates of growth in each of these sectors, however, have been substantially less than the period prior to 1979. Although there are many reasons for this change, it is likely that increasing energy efficiency played a significant role. Furthermore, the study mentioned above along with other, ongoing Academy work suggest that there are a number of research opportunities for increasing energy efficiency for a broad range of technologies. Nevertheless, while past and projected energy efficiency can contribute to at least a slowing of carbon emissions from electricity generation, by itself, it is not likely to stop the growth in such emissions. A 1999 report by the Congressional Research Service, *Global Climate Change: Carbon Emissions and End-use Energy Demand* (RL30036) discusses this issue in more detail.

Research on sequestration of carbon dioxide from the combustion of coal for electric power production could be a very important step for halting the growth in carbon emissions. Clean coal technology and IGCC were initially developed to minimize emissions of air pollutants, such as sulfur dioxide. These technologies can contribute to carbon emission reductions only to the extent that they increase the efficiency of coal combustion and, possibly, make it easier to integrate carbon dioxide sequestration technology. The latter has significant potential for reducing carbon emissions, but its success is still uncertain. Commercial, large-scale carbon sequestration is many years away, at best, and research to reach this goal is important (Socolow, 2005). A National Academies' workshop report, *Novel Approaches to Carbon Management: Separation, Capture, Sequestration, and Conversion to Useful Products*, presented a discussion of a number of new research areas to attack this problem. Until commercial sequestration technologies are available, however, carbon emission reductions can probably best be achieved by encouraging the construction of natural-gas fired generation plants instead of coal. The domestic supply of natural gas ap-

[1] This report presents an analysis of a number of Department of Energy energy efficiency and fossil fuel combustion technology research programs.

pears to be limited, and production increases may not be possible much longer. Therefore to continue this path towards constraining carbon emissions, increasing the importation of natural gas, generally in the form of liquefied natural gas (LNG), probably is essential.

In formulating a national strategy for minimizing CO_2 emissions from energy production and use, we should consider a range of technology options, from improving energy efficiency to carbon sequestration to nuclear energy. It is important to clearly and carefully develop reasonable expectations of potential emissions reductions associated with the full suite of technology options.

Question 2. While you have presented what appears to be a united scientific front in the form of the statement from the academies of science from 11 countries, I am concerned by some of the news since the release of that statement. The Russian Academy of Sciences says it was misrepresented and that Russian scientists actually believe that the Kyoto Protocol was scientifically ungrounded. I am also aware that there was a significant misrepresentation on the science between our academy and the British representative. Given this background, wouldn't you say there are still some pretty fundamental disagreements about the science of climate change among scientists around the world?

Answer. No, disagreements about the underlying science are actually relatively minor. The statement agreed to by the science academies of the G8 nations, China, India, and Brazil makes this quite clear. The full statement can be viewed at *http://www.nationalacademies.org/morenews/20050607.html*. Note also that the statement does not address the relative merits of the Kyoto Protocol. Disagreements remain between governments in terms of determining an appropriate policy response.

Question 3. In this international academies statement, you find that an "immediate response that will, at a reasonable cost, prevent dangerous anthropogenic interference with the climate system," but continue to say in the following paragraph, "minimizing the amount of this carbon dioxide reaching the atmosphere presents a huge challenge." Could you please elaborate, since any response can't both be a "reasonable cost" and a "huge challenge" proposition, how you resolve the two?

Answer. The question has taken out of context two phrases from the statement produced by the science academies of the G8 nations, Brazil, China and India. The two paragraphs in full are as follows:

> "Action taken now to reduce significantly the build-up of greenhouse gases in the atmosphere will lessen the magnitude and rate of climate change. As the United Nations Framework Convention on Climate Change (UNFCCC) recognises, a lack of full scientific certainty about some aspects of climate change is not a reason for delaying an immediate response that will, at a reasonable cost, prevent dangerous anthropogenic interference with the climate system.
>
> As nations and economies develop over the next 25 years, world primary energy demand is estimated to increase by almost 60%. Fossil fuels, which are responsible for the majority of carbon dioxide emissions produced by human activities, provide valuable resources for many nations and are projected to provide 85% of this demand (IEA 2004). Minimising the amount of this carbon dioxide reaching the atmosphere presents a huge challenge. There are many potentially cost-effective technological options that could contribute to stabilising greenhouse gas concentrations. These are at various stages of research and development. However barriers to their broad deployment still need to be overcome."

In the first paragraph above, the goal of preventing dangerous anthropogenic interference with the climate system is identified and the second paragraph recognizes that this is a challenging goal, for which potential technological options are becoming available, but not yet widely deployed. Indeed, the statement of the eleven national science academies recommends several actions to work towards meeting the goal:

- "Identify cost-effective steps that can be taken now to contribute to substantial and long-term reduction in net global greenhouse gas emissions. Recognise that delayed action will increase the risk of adverse environmental effects and will likely incur a greater cost.
- Work with developing nations to build a scientific and technological capacity best suited to their circumstances, enabling them to develop innovative solutions to mitigate and adapt to the adverse effects of climate change, while explicitly recognising their legitimate development rights.
- Show leadership in developing and deploying clean energy technologies and approaches to energy efficiency, and share this knowledge with all other nations."

Question 4. Several scientists have cited events like the high temperatures in Europe in the summer of 2003 and increased storminess in the 1980s and 1990s as evidence of climate change. Don't global ecosystems go through natural periods similar to these as well?

Answer. Yes, climate variability is known to have occurred throughout Earth's history, presumably due to natural causes. Scientists have hypothesized that human-caused global warming will lead to more frequent and more severe extreme events, including heat waves, severe storms, and hurricanes. A recent climate modeling study found that European heat waves in the latter half of the 21st century may be more intense, more frequent, and longer lasting than those of the late 20th century (Meehl and Tebaldi, 2004). However, it is not possible to determine definitively whether events such as the 2003 European heat wave are due to human or natural causes.

Question 5. There are a number of astrophysicists and other scientists who believe that sunspots are a major contributor to changing temperatures. A recent survey showed at least 100 such studies are underway. Why don't scientists put as much emphasis on this possibility or other aspects of natural climate variability as they do on emissions from human activity?

Answer. Actually, scientists have conducted significant research on natural climate variability, including how solar variability, volcanoes, the biosphere, weathering of rocks, and other natural processes can affect climate. Research on climate variability also addresses multiple modes of natural variability in the climate system, such as the El Niño Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), and the Pacific Decadal Oscillation (PDO), and the extent to which these longer term (multi-year to multi-decadal) variations might explain recent trends. So far, none of these processes have been able to explain the increases in global mean temperature observed since the late 1970s.

The extent to which variations in the Sun might contribute to recent observed warming trends is an area of active research. The Sun's brightness—its total irradiance—has been measured continuously by a series of satellite-based instruments for more than two complete 11-year solar cycles. These multiple solar irradiance datasets have been combined into a composite time series of daily total solar irradiance from 1979 to the present. Different assumptions about radiometer performance lead to different reconstructions for the past two decades. Recent analyses of these measurements, taking into account instrument calibration offsets and drifts, argue against any detectable long-term trend in the observed irradiance to date. Likewise, models of total solar irradiance variability that account for the influences of solar activity features—dark sunspots and bright faculae—do not predict a secular change in the past two decades. Thus, it is difficult to conclude from either measurements or models that the Sun has been responsible for the warming observed over the past 25 years, although this hypothesis was more plausible before the availability of more recent evidence.

Knowledge of solar irradiance variations prior to the commencement of continuous space-based irradiance observations in 1979 is rudimentary. Models of sunspot and facular influences developed from the contemporary database have been used to extrapolate daily variations during the 11-year cycle back to about 1950 using contemporary sunspot and facular proxies, and with less certainty annually to 1610. Circumstantial evidence from cosmogenic isotope proxies of solar activity (^{14}C and ^{10}Be) and plausible variations in Sun-like stars motivated an assumption of long-term secular irradiance trends, but recent work questions the evidence from both (Lean et al., 2002). Very recent studies of the long term evolution and transport of activity features using solar models suggest that secular solar irradiance variations may be limited in amplitude to about half the amplitude of the 11-year cycle.

Question 6. Much of the discussion about climate science being settled is based on the summary chapter of the Intergovernmental Panel on Climate Change of the United Nations. The chapter made specific predictions about the pace of rising temperatures and the relative importance of human activities to climate change. And yet, the body of the report is much more ambiguous and inconclusive about the current state of the science. Is anything being done to ensure that the summary of the next IPCC report is more reflective of the overall analysis by the scientists?

Answer. Certainly some nuance will be lost when summarizing hundreds of pages of detailed text in a 59-page Technical Summary or a 17-page Summary for Policymakers, as was the case for the Working Group I portion of the IPCC Third Assessment Report (IPCC, 2001a). Yet, it is not clear that the summaries represented the state of science differently than the full text. The 2001 NRC report *Climate Change Science* concluded the following:

"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." (NRC, 2001a)

Another IPCC assessment is underway now, with the reports due to be released in 2007. It is our understanding that similar measures will be taken to ensure that the summaries accurately reflect the body of the report. For this Fourth Assessment Report, Working Group I is co-chaired by Susan Solomon, a highly respected scientist employed by the U.S. National Oceanic and Atmospheric Administration (NOAA).

Question 7. The natural "greenhouse effect" has been known for nearly two hundred years and is essential to the provision of our current climate. There is significant research in the literature today that indicates humans, since the beginning of their existence, have caused an increase in the greenhouse effect. Some argue that the development of agriculture 6,000 to 8,000 years ago has helped to forestall the next ice age. The development of cities, thinning of forests, population growth, and most recently the burning of fossil fuels, have all had an impact on climate change. Our ecosystems have constantly adapted to change, as we as humans have adapted to our ecosystems as well. Is it possible that the increased presence of CO_2 caused by the 8,000 years of modern human existence may be something our ecosystems will continue, as they previously have, to naturally adapt to?

Answer. Yes, many ecosystems and human systems will likely be able to adapt to some of the changes associated with global warming. But, CO_2 and other greenhouse gases have increased much more rapidly in the past century than at any other time for which we have clear documentation and the levels of these gases are higher than at anytime in the last 420,000 years (Petit et al., 1999). Thus, greenhouse warming is happening more rapidly than ecosystems are accustomed to.

It is not clear how well natural systems will be able to adapt to this more rapid and significant change. It is likely that there will be major disruptions to some ecosystems and that terrestrial plant and animal species will be unable to migrate quickly enough to accommodate regional climatic changes. Without intervention, it is likely that more species will become endangered in the coming decades due to climatic changes in habitat combined with human-caused fragmentation of habitats and restriction of migration routes. Habitats of marine species are expected to shift poleward, with an expansion in habitat for warm-water species and a decrease in habitat for cold-water species. (IPCC, 2001b)

Question 8. Dr. Cicerone, you said that "Observations and data are the foundation of climate change science." Yet observational data is available for at best the past 140 years. And reconstructive climate data for the last 2000 years offers widely divergent conclusions as to timing of trends, peaks and troughs. Climate change is a phenomenon most apparent over significantly larger time periods. While the panel before us presented temperature and CO_2 level reconstruction that paints the 20th century as one-time anomaly, could you summarize the research that indicates contrary positions? Isn't it true that at previous times in the earth's history CO_2 emissions have been exponentially higher than current levels?

Answer. Actually, observations of the last 2000 years do not offer widely divergent conclusions as to the timing of trends, peaks, and troughs. In fact, all the estimates of global mean observed surface temperature of the past 1000 years show a rapid increase in the last 100 years, with particularly significant warming in the last 30 years reaching maximum temperatures in the late 1990s and early 21st century. This result has been demonstrated by many different groups of scientists using different assumptions and methodologies (see Figure 1).* It is consistent with direct measurements of the greenhouse gases CO_2 and CH_4 extracted from ice cores.

Global mean temperatures over geological timescales are hypothesized to have been much warmer (and much colder) at times. Based on models and inferences about atmospheric composition from geological data, it is thought that the early Earth (i.e., billions of years ago) was warmed by a high concentration of greenhouse gases, probably mainly CO_2, perhaps in the range of a few hundred to 1000 times present atmospheric levels (Kump et al., 2000). To explain such high levels of atmospheric CO_2, most attention has focused on the dominant process that draws down atmospheric CO_2 relative to production on geological timescales: the chemical weathering of continental silicate rocks. In a planet with much less exposed land mass, this removal process for CO_2 would be much slower, allowing CO_2 to build up in the atmosphere. It should be emphasized, however, that this hypothesis is based largely on models and inference rather than conclusive proxy evidence. Also, the changes associated with global warming are happening at a much more rapid pace than those that may have happened on geological timescales.

Geological evidence also suggests that atmospheric CO_2 changed dramatically on timescales of a few to tens of millions of years during much of the Phanerozoic eon (from about 540 million years ago until 20 million years ago). The record suggests that for at least two-thirds of the last 400 million years, levels of atmospheric CO_2 were 5-10 times higher than at present. It appears that these oscillations in atmospheric CO_2 were linked to recurring changes from greenhouse to icehouse climate states (Berner and Kothavala, 2001; Royer et al., 2004).

Question 9. The panel touched on some energy alternatives such as biomass, natural gas, and nuclear power, yet there was little mention of hydrogen power. From a scientific viewpoint, where do you think we are on being able to really utilize hydrogen power? What is the potential of hydrogen power?

Answer. Hydrogen, like electricity, is an energy carrier, not a primary fuel. It must be made from other energy sources. It has the potential for reducing carbon emissions if it is generated from non-fossil energy (nuclear or renewables) or if the carbon from fossil fuel sources is sequestered. The National Academies has recently issued two major reports on the subject of hydrogen covering the potential of future technologies for its production, as well as its use in transportation and stationary applications: *The Hydrogen Economy—Opportunities, Costs, Barriers, and R&D Needs* (2004), and *Review of the Research Program of the Freedom CAR and Fuel Partnership* (2005). Transforming the current petroleum-based transportation system, for example, to a clean, hydrogen-fueled system is extremely challenging requiring a fundamental transformation of automotive technologies and the supporting fuel infrastructure. Even if all the technical challenges are met, transitioning from the current fuel infrastructure based on gasoline and diesel fuel to one based on hydrogen derived from a variety of sources (e.g., coal, natural gas, solar, wind, biological conversion, nuclear) will be a formidable social and economic challenge. Research and development in support of such a transformation is justified by the potentially enormous beneficial impact to the nation.

Much progress has been made in many hydrogen technologies, such as fuel cells. Nevertheless, many technical barriers exist and need to be overcome, and fundamental invention is probably needed to achieve performance and cost levels that will lead to cost competitive hydrogen and commercially acceptable vehicles. For example, fuel cells face performance, durability, efficiency and cost issues, and hydrogen storage for onboard vehicles faces difficult size, weight and cost barriers. Even assuming that the technical and cost targets for commercial readiness could be met in the 2015 to 2020 time frame, it would take many decades for the turnover of the vehicle fleet in order to have a significant impact on carbon emissions from the transportation sector. This implies that the conventional internal combustion engine will be the automotive power plant that consumes most of the fuel in the vehicle fleet for several decades to come and improving technology to reduce fuel consumption and emissions from internal combustion engines is, therefore, critically important as well.

Question 10. The panel established very clearly that we should adopt policies that decrease carbon emissions regardless of any other carbon emissions policies we pursue. We are currently or will shortly be providing expanded incentives for clean coal, nuclear energy and renewable fuels. Do you feel this is money well spent? What technologies do you feel the government should be more involved in developing?

* Retained in committee files.

Answer. Nuclear and renewable energy technologies release very little carbon. As noted above, clean coal technology and IGCC coupled with full sequestration can also result in little or not carbon emissions. All of these technologies, however, have drawbacks. The economic competitiveness of nuclear energy is still questionable compared to current fossil technologies under existing regulatory conditions, and issues of nuclear waste and public acceptance still remain. Only a few renewable energy technologies are economic at this time, and then only at particularly favorable sites. Also, as noted, the successful development of carbon sequestration is uncertain. Nevertheless, these are our options for carbon-free fuels.

In the transportation sector, it will also be important to understand the competition that will arise between electricity-based, liquid-fuel-based (e.g., cellulosic ethanol), and hydrogen-based transportation technologies. This is particularly important as clean alternative combustion engines and hybrid vehicles, fuel cells, and batteries evolve. Understanding which pathway, or combination of pathways, will provide the best opportunities for reducing CO_2 emissions and improving energy security will require a balanced research and development portfolio and extensive systems analysis.

In all of these cases, continued research and development is important. There remains, however, the question of how best to pursue the goal of reducing carbon emissions. A systematic, comprehensive comparison of the options described in the above three questions has not been done. Such an analysis would have to account for the complex array of economic, technical, environmental, regulatory, and public acceptance issues that affect each of the options. With the results of this assessment in hand, policy choices that provide effective incentives for the most promising carbon management options are more probable.

RESPONSES OF RALPH J. CICERONE TO QUESTIONS FROM SENATOR TALENT

Question 1. The Academies letter says that it is "likely" that man is the cause of global warming—what exactly do we know, and what are we inferring from the data we have? How well to the models of today replicate actual observed climate patterns of recent times? What margin of error do you attach to the best models we have today?

Answer. It is likely that most of the global mean surface temperature increase since the late 1970s is due to human activities. This conclusion is consistent with that reached by Intergovernmental Panel on Climate Change (IPCC) in their 2001 assessment of the scientific literature and the 2001 report of the NRC *Climate Change Science: An Analysis of Some Key Questions.*

This conclusion is generally based on studies that compare the observed climate record from 1860 to today with global mean temperature simulated in three computational climate model scenarios:

1) Only natural variability (due to solar and volcanic variability)
2) Only anthropogenic variability (due to greenhouse gases and aerosols)
3) Both natural and anthropogenic variability

In these studies, the models run with only natural variability are unable to reproduce the warming observed since the late 1970s, typically showing no trend over this time period (e.g., Stott et al., 2000; Meehl et al., 2004). Thus, we conclude that human-caused climate forcings have disrupted Earth's energy balance, causing an increase in global mean surface temperatures (NRC, 2005).

Improved understanding of the natural variability of the climate system supports the conclusion that human activities are mostly responsible for global temperature increases of the past three decades. In particular, new studies of solar variability show that there has been little if any trend in the Sun's brightness over the past 25 years, ruling out solar variability as a major driver of observed warming (see Response to #2 for more details).

Because of the still uncertain level of natural variability inherent in the climate record and the uncertainties in the time histories of the various forcing agents, a causal linkage between the buildup of greenhouse gases in the atmosphere and the observed climate changes during the 20th century cannot be unequivocally established. The fact that the magnitude of the observed warming is large in comparison to natural variability as simulated in climate models is suggestive of such a linkage, but it does not constitute incontrovertible proof of one because the model simulations could be deficient in natural variability on the decadal to century time scale.

Question 2. There are a number of astrophysicists and other scientists who believe that sunspots are a major contributor to changing temperatures. A recent survey showed at least 100 such studies are underway. Why don't scientists put as much emphasis on this possibility or other aspects of natural climate variability as they do on emissions from human activity?

Answer. Actually, scientists have conducted significant research on natural climate variability, including how solar variability, volcanoes, the biosphere, weathering of rocks, and other natural processes can affect climate. Research on climate variability also addresses multiple modes of natural variability in the climate system, such as the El Niño Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), and the Pacific Decadal Oscillation (PDO), and the extent to which these longer term (multi-year to multi-decadal) variations might explain recent trends. So far, none of these processes have been able to explain the increases in global mean temperature observed since the late 1970s.

The extent to which variations in the Sun might contribute to recent observed warming trends is an area of active research. The Sun's brightness—its total irradiance—has been measured continuously by a series of satellite-based instruments for more than two complete 11-year solar cycles. These multiple solar irradiance datasets have been combined into a composite time series of daily total solar irradiance from 1979 to the present. Different assumptions about radiometer performance lead to different reconstructions for the past two decades. Recent analyses of these measurements, taking into account instrument calibration offsets and drifts, argue against any detectable long-term trend in the observed irradiance to date. Likewise, models of total solar irradiance variability that account for the influences of solar activity features—dark sunspots and bright faculae—do not predict a secular change in the past two decades. Thus, it is difficult to conclude from either measurements or models that the Sun has been responsible for the warming observed over the past 25 years, although this hypothesis was more plausible before the availability of more recent evidence.

Knowledge of solar irradiance variations prior to the commencement of continuous space-based irradiance observations in 1979 is rudimentary. Models of sunspot and facular influences developed from the contemporary database have been used to extrapolate daily variations during the 11-year cycle back to about 1950 using contemporary sunspot and facular proxies, and with less certainty annually to 1610. Circumstantial evidence from cosmogenic isotope proxies of solar activity (^{14}C and ^{10}Be) and plausible variations in Sun-like stars motivated an assumption of long-term secular irradiance trends, but recent work questions the evidence from both (Lean et al., 2002). Very recent studies of the long term evolution and transport of activity features using solar models suggest that secular solar irradiance variations may be limited in amplitude to about half the amplitude of the 11-year cycle.

Question 3. Is it true that the Canadian Climate Center study and the U.K. Hadley Center studies used by the Clinton Administration to justify Kyoto were the two that predicted the most extreme results? Is it also true that Dr. Pat Michaels and Tom Karl of NOAA independently confirmed that these models could not reproduce past U.S. temperature trends over any averaging period (e.g., 5, 10, or 25 year periods)? Didn't the Canadian model over-predict warming by 300%?

Answer. To my knowledge, the Clinton Administration never used any specific models to "justify Kyoto." The U.S. National Assessment of Potential Climate Change Impacts (NAST, 2000) did use climate scenarios from both the Canadian Climate Center (CCC) and the U.K. Hadley Center in its analyses, along with several other models and historical data. The National Assessment, which fulfills the requirements of the U.S. Global Change Research Act of 1990, evaluated the potential risk to the United States from climate impacts if greenhouse gas emissions continued on a business-as-usual trajectory. It did not consider any Kyoto-based analyses. The two models were selected by the National Assessment Synthesis Team (NAST), an independent, non-governmental committee for several reasons:

1) They were published and part of the international debate leading to the IPCC reports, also completed in 2001.

2) The model computations covered the period from 1895 to 2100, allowing the National Assessment to (a) compare model results and historical observations to judge the veracity of the simulations and (b) examine future climate conditions projected by the models.

3) They preserved model results on a daily basis (rather than monthly means, for example), allowing the National Assessment to include ecosystem impact analysis.

4) They provided access to all the available model results.

5) They bracketed the range of model simulations or, in other words, they were far from the most extreme results. The CCC model was one of the warmer models in the IPCC family, whereas the Hadley Center model was at the lower

end of the spectrum, but somewhat closer to the middle (see NAST, 2001, p. 31-40).

These two models were not the only ones used in the National Assessment. Some participants also used the National Center for Atmospheric Research (NCAR) Climate System Model, however it was not ready until part way through the assessment so not every group included it. At the time, U.S. modeling capabilities were lagging behind some other countries, in part because of a shortfall in computing facilities and highly skilled technical workers devoted to climate modeling (NRC, 2001b). In addition to global models, some participants in the National Assessment also looked at historical analogues or regional model simulations.

In regard to the questions about the accuracy of the models, it is important to note that all global climate models have some flaws. All the models used in the National Assessment were compared to observations to judge their ability to simulate the last 100 years. All the available models suggest a warming range of 0.4 to 0.8° C over the 20th century, which is the same range as the observations. The Hadley model predicts 0.55° C and the Canadian 0.7° C, well within the observed range. The Canadian model did not over-predict 20th century global mean temperature trends by 300%. Most models of this generation captured the ups and downs of the observed record of the last 100 years when they included the impacts of solar variability, greenhouse gases, and aerosols. However, they were not designed in a way to perfectly reproduce the year-to-year variation for a specific region over any period of years in the 20th century. Thus, conclusions in the National Assessment about interannual variation were not based on the global model results.

Question 4. To what degree can we attribute warming to controllable GHG emissions, i.e., what portion of the observed warming is due to human emissions?

Answer. It is likely that most of the global mean surface temperature increase since the late 1970s is due to human activities. This conclusion is consistent with that reached by Intergovernmental Panel on Climate Change (IPCC) in their 2001 assessment of the scientific literature and the 2001 report of the NRC Climate Change Science: An Analysis of Some Key Questions.

This conclusion is generally based on studies that compare the observed climate record from 1860 to today with global mean temperature simulated in three computational climate model scenarios:

1) Only natural variability (due to solar and volcanic variability)
2) Only anthropogenic variability (due to greenhouse gases and aerosols)
3) Both natural and anthropogenic variability

In these studies, the models run with only natural variability are unable to reproduce the warming observed since the late 1970s, typically showing no trend over this time period (e.g., Stott et al., 2000; Meehl et al., 2004). Thus, we conclude that human-caused climate forcings have disrupted Earth's energy balance, causing an increase in global mean surface temperatures (NRC, 2005).

Question 5. Assuming the technology was available today, what would be the necessary GHG emissions cuts in the U.S.A to stop the warming and level out global temperatures? Does this assume no increases in emissions by developing nations?

Answer. Carbon dioxide can remain in the atmosphere for many decades and major parts of the climate system respond slowly to changes in greenhouse gas concentrations. Although carbon dioxide is the most significant greenhouse gas perturbed by humans, other anthropogenic greenhouse gases also have an important impact on climate. These include (1) methane, for which concentrations have increased by about a factor of 2.5 since preindustrial times, but have stopped increasing more recently for unknown reasons; (2) halocarbons such as chlorofluorocarbons, whose emissions were controlled because they contribute to ozone depletion in the stratosphere; and (3) nitrous oxide, which continues to rise.

Even if greenhouse gas levels were stabilized instantly at today's levels, the climate would still continue to change as it adapts to the increased emissions of recent decades, as illustrated in Figure 1. For current models with a midrange climate sensitivity and average assumptions about the greenhouse effects of atmospheric aerosols, Wigley (2005) estimates that global mean surface temperatures will increase by about 0.4° C over the next 400 years, with most of the warming occurring within the first 100 years (see the center red line in Figure 1).* Thus, even with no greenhouse gas emissions from this point forward, we would be experiencing the impacts of climate change throughout the 21st century and beyond.

Because instantly stopping all greenhouse gas emissions is unrealistic, scientists have considered what steps would be necessary to stabilize atmospheric CO_2 levels

*Retained in committee files.

at several targets ranging from 450 ppm to 1000 ppm (compared to today's levels of 380 ppm and pre-industrial concentrations of 280 ppm). Depending on the target, a range of emissions cuts are required by developed and developing countries. For example, Wigley (1997) found that to achieve CO_2 stabilization at 550 ppm, developed countries would need to begin reducing emissions 1% a year by 2010 and developing countries would need to do so by 2030. Note that stabilizing CO_2 concentrations at 550 ppm is estimated to lead to a global mean temperature increase of about 2.5° C over 1990 levels in 2150 (IPCC, 2001).

Question 6. The statement from the academies of science from 11 countries has turned out to be quite controversial. The Russian Academy of Sciences says it was misrepresented in the statement and that Russian scientists actually believe that the Kyoto Protocol was scientifically ungrounded. Also, the president of the American Academy has complained that his British counterpart misrepresented the U.S. view of the science and that there might be an end to future collaboration between U.S. and British scientists. Aren't there still some pretty fundamental disagreements about the science of climate change among scientists around the world?

Answer. No, disagreements about the underlying science are actually relatively minor. The statement agreed to by the science academies of the G8 nations, China, India, and Brazil makes this quite clear. The full statement can be viewed at *http://www.nationalacademies.org/morenews/20050607.html*. Note also that the statement does not address the relative merits of the Kyoto Protocol. Disagreements remain between governments in terms of determining an appropriate policy response.

Question 7. The 4th paragraph of the joint science academies' statement talks about undertaking an "immediate response that will, *at a reasonable cost*, PREVENT dangerous anthropogenic interference with the climate system." But the 5th paragraph says, "minimizing the amount of this carbon dioxide reaching the atmosphere presents a *huge challenge*." Since it can't be both, would you describe the measure you would endorse as a "reasonable cost" proposition or a "huge challenge"?

Answer. The question has taken out of context two phrases from the statement produced by the science academies of the G8 nations, Brazil, China and India. The two paragraphs in full are as follows:

> "Action taken now to reduce significantly the build-up of greenhouse gases in the atmosphere will lessen the magnitude and rate of climate change. As the United Nations Framework Convention on Climate Change (UNFCCC) recognises, a lack of full scientific certainty about some aspects of climate change is not a reason for delaying an immediate response that will, at a reasonable cost, prevent dangerous anthropogenic interference with the climate system.
>
> As nations and economies develop over the next 25 years, world primary energy demand is estimated to increase by almost 60%. Fossil fuels, which are responsible for the majority of carbon dioxide emissions produced by human activities, provide valuable resources for many nations and are projected to provide 85% of this demand (IEA 2004)3. Minimising the amount of this carbon dioxide reaching the atmosphere presents a huge challenge. There are many potentially cost-effective technological options that could contribute to stabilising greenhouse gas concentrations. These are at various stages of research and development. However barriers to their broad deployment still need to be overcome."

In the first paragraph above, the goal of preventing dangerous anthropogenic interference with the climate system is identified and the second paragraph recognizes that this is a challenging goal, for which potential technological options are becoming available, but not yet widely deployed. Indeed, the statement of the eleven national science academies recommends several actions to work towards meeting the goal:

- "Identify cost-effective steps that can be taken now to contribute to substantial and long-term reduction in net global greenhouse gas emissions. Recognise that delayed action will increase the risk of adverse environmental effects and will likely incur a greater cost.
- Work with developing nations to build a scientific and technological capacity best suited to their circumstances, enabling them to develop innovative solutions to mitigate and adapt to the adverse effects of climate change, while explicitly recognising their legitimate development rights.
- Show leadership in developing and deploying clean energy technologies and approaches to energy efficiency, and share this knowledge with all other nations."

Question 8. If all the countries that have signed Kyoto stay within compliance of Kyoto, how much of a reduction in global warming would this result in?

Answer. Estimates for warming between 1990 and 2100 range from 1.4 to 5.8° C (IPCC, 2001). In the analysis of Reilly et al. (1999), if all nations complied with the Kyoto Protocol, global mean surface temperatures would be about 0.5° C less than if no intervention is taken. At the treaty's implementation in February 2005, the agreement had been ratified by 141 countries representing about 60% of global emissions. Thus, the Kyoto Protocol as currently being implemented, might be expected to reduce future warming by about 0.3° C by 2100.

Question 9. Can you confirm that suspended water vapor levels, cloud cover percentages and direct solar irradiation changes over time all represent variables in these forecasting models that could have significant impacts on the conclusions of the results of these models?

Answer. Yes, water vapor, cloud cover, and solar irradiation are important variables that all climate models incorporate.

Question 10. In looking at pre-industrial global temperature patterns, would you agree that changes in temperatures over time have occurred that had no anthropogenic basis?

Answer. Yes, pre-industrial temperature showed natural climate variability, likely due to solar variability, volcanoes, the biosphere, weathering of rocks, and other natural processes. There are also multiple modes of natural variability in the climate system, such as the El Niño Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), and the Pacific Decadal Oscillation (PDO), which cause longer term (multi-year to multi-decadal) variations.

Question 11. Do we know what the "best" global temperature is to sustain life?

Answer. No, but we do know that human systems have developed in a way to take advantage of current climate conditions. We live and have built major infrastructure along coastlines, assuming that sea levels will not change significantly. We have developed agricultural lands in locations that current climate conditions favor. We have constructed elaborate systems to distribute fresh water that depend on current snow pack levels, rainfall amounts, and river flows. These and other major infrastructural investments are not easily or quickly shifted. Thus, while humans—especially those who live in richer and more educated countries—will no doubt be able to adapt, it is unlikely that they could do so without exacting economic, health, and other tolls.

Question 12. What is currently being done to curb emissions from parts of the world in poverty who are deforesting their environment and burning biomass for all means of day-to-day living, and are these emissions continuing to increase in the world?

Answer. I am not familiar with efforts to control biomass burning emissions in developing countries. Based on satellite observations of large fires, Duncan et al. (2003) found no significant trends in emissions from burning of forests and grasslands over the past two decades. Their analysis did not consider emissions from burning biofuel (e.g., wood, agricultural waste) for day-to-day living. Streets et al. (2001) analyzed greenhouse gas emissions from China over the 1990s and found a slow decline in emissions from the use of biofuel for cooking and heating.

Question 13. Do you believe it is practical to seek emission controls in parts of the world that are struggling in poverty?

Answer. Whether to seek emission controls in impoverished parts of the world is largely a policy decision, for which science and technology can inform only part of the answer. Certainly, higher quality fuels and better developed technology for using those fuels provide greater energy output and less pollution. So, there are compelling reasons for curbing emissions in these countries in addition to addressing global warming.

Question 14. What is being done to curb emissions in the developing countries like China and India?

Answer. Streets et al. (2001) analyzed greenhouse gas emissions from China over the 1990s and found that emissions increased significantly from 1990 until about 1996, when they began decreasing until 2000. They attribute the decrease to a radical reform of China's coal and energy industries, as well as the economic downturn in China associated with the Asian economic crisis of 1997-1998. At the time, the authors predicted that as China's economy recovered from the economic downturn and completed major reforms, rates of greenhouse gas emissions would begin to slowly increase. More recently, China has taken several steps to begin controlling their greenhouse gas emissions, including:

- In October, 2004 China enacted their first fuel efficiency standards for new passenger cars (see *http://www.usatoday.com/money/world/2004-10-08-china-*

fuel-efficiency__x.htm). The first phase began this summer. The second phase begins in 2008 and mandates a 10% improvement. Unlike U.S. standards which regulate corporate averages, the Chinese standards set a maximum fuel consumption rate for every vehicle sold, with the rate varying for 32 different car and truck weight classes.

- In January 2005, the National Development and Reform Commission (NDRC) published the China Medium and Long Term Energy Conservation Plan which targets an average annual reduction of 2.2% in energy intensity to 2010. The main thrust of the plan is to give priority to energy conservation over development of new energy sources.
- In March, 2005 China enacted a renewable energy law requiring an increase in consumption of renewable energy from current levels of about 3% to 10% by 2020. My understanding is that renewable energy in the law includes hydroelectricity, wind power, solar energy, geothermal energy and marine energy. (See *http://www.renewableenergyaccess.com/assets/download/China__RE__Law__05.doc*)
- China's Air Conditioner Energy Efficiency Standards have recently been tightened by 10-20%

Emissions from India have increased significantly over the past several decades as the country has become more industrialized. Analyses by Shukla et al. (e.g., 2003) indicate that a portfolio of strategies—including increasing efficiency, upgrading transportation systems, and penetration of renewable and nuclear energy sources—will likely be necessary to control emissions as India's economy and population expand in the coming decades. I am not familiar with specific measures to control emissions in India.

RESPONSES OF RALPH J. CICERONE TO QUESTIONS FROM SENATOR FEINSTEIN

Question 1. Is there any credible scenario for stabilizing greenhouse gas emissions that does not involve the United States and other major emitters stopping their emissions growth over the next couple of decades and sharply reversing their emissions growth by 2050?

Answer. Stabilizing CO_2 concentrations in the atmosphere requires CO_2 emissions to drop well below current levels. Although the ocean has the capacity to uptake 70 to 80% of foreseeable anthropogenic CO_2 emissions, this process takes centuries due to the slow rate of ocean mixing. It is hard to envision any scenario for stabilizing greenhouse gas emissions and the resultant concentrations of these gases in the atmosphere that does not involve significant emissions reductions by major emitters.

Question 2. Would the National Commission on Energy Policy's proposal stop and then reverse U.S. greenhouse gas emissions?

Answer. My understanding is that the proposal by the National Commission on Energy Policy aims to slow, stop, and then reverse growth in the rate of greenhouse gas emissions. Under the proposal, total annual emissions would continue to increase until around 2020, then level out, and eventually start to decrease.

RESPONSES OF SIR JOHN HOUGHTON TO QUESTIONS FROM SENATOR BINGAMAN

Question 1. Over the last several decades, anthropogenic emissions have "substantially contributed" to the increase in average global temperatures. Upon receiving a question from one of the Senators, one of the panelists suggested that "80 percent" of the warming was due to human activities. Do all the panelists agree? Please provide information as to how this estimate was derived.

Answer. I was not the panelist that quoted the 80%. It is, however, close to the estimate that I have also often quoted quite independently and arrived at as follows. In answering the question of how much of the recent warming is due to human activities there are two relevant considerations: (1) estimates of radiative forcing and (2) estimates of natural variability. I deal with these in turn.

ESTIMATES OF RADIATIVE FORCING

It is the radiative forcings that are driving change. For the latest estimates of radiative forcings I refer to the paper by J. Hansen et al., Earth's Energy Imbalance: Confirmation and Implications, in Sciencexpress for 2 May 2005—a paper that provides more detail and updates similar information in Fig 3 in the Summary for Policymakers (SPM) and in chapter 6 of the IPCC 2001 Report, *Climate Change 2001: the Scientific Basis*.

'Natural' forcings are mainly those due to volcanoes (in Hansen's paper the blue line labelled stratospheric aerosols—because it is dust in the stratosphere that causes forcings from volcanoes) and changes in solar irradiance. The estimated solar irradiance change of about 0.2 watts per square metre occurred mostly in the first half of the 20th century and is believed to be a significant factor in leading to the warming during that period. Changes in solar radiation in the second half of the century are small as indicated from measurements from satellite instruments since the 1970s.

The other forcings are almost entirely anthropogenic (apart from a small component of black carbon from 'natural' forest fires). Note that greenhouse gases provide by far the largest positive (warming) forcing and that significant negative (cooling) forcing comes from anthropogenic aerosols. This latter is sometimes called global dimming as it tends to offset some of the greenhouse gas warming. Note that by far the largest contribution to radiative forcing over the last 50 years comes from increases in greenhouse gases and that at least 95% of the positive (warming) forcing over this period comes from human activities. Note also that most of the negative forcing is also of human origin and that this will reduce if, as is expected, sulphur dioxide (that leads to reflective tropospheric aerosol formation) pollution controls become more severe during coming decades.

Fig 1B in the Hansen et al. paper compares model simulations of surface temperature change over the 20th century, that include all the forcings of Fig 1A, with observations of surface temperature change. It should be compared with Fig 4 in the SPM of the IPCC 2001 Report. It deals more comprehensively and accurately with the various forcings than did the IPCC Report and extends them to the present. It shows a remarkable degree of agreement between simulations and observations.

ESTIMATES OF NATURAL VARIABILITY

Looking at estimates of anthropogenic radiative forcing enables us to establish that the observed warming over the last 50 years is entirely consistent with it being due almost entirely to human activities. However, it is known that the global average temperature and hence the climate can also change due to unforced variations that occur because of variations within the climate system itself. Estimates of such natural variability come from long climate model simulations that agree reasonably well with such variability found in observational studies (as explained in chapters 8 and 12 of the IPCC 2001 Report). Such studies show that more than about 20% of the rise in global average temperature since 1950 of about 0.45° C is very unlikely (less than 10% probability) to come from natural unforced variability.

Taking these two considerations together leads to the conclusion that it is very likely (greater than 90% probability) that at least 75% of the warming over the last 50 years in due to human activities.

Question 2. We received testimony that sought to distinguish between average global temperature changes causes primarily by anthropogenic emissions and local/regional temperature changes caused at times by natural variation. Please explain in greater detail.

Answer. The climate shows natural variability (i.e. unforced variability—see answer to question 1) in all climate characteristics (temperature, precipitation, humidity, wind speed, etc.) and on all time and space scales. The shorter the time scale and the smaller the space scale the larger is this variability. That is why it is easier to identify trends in climate due to anthropogenic emissions in annual and global averages of quantities such as temperature rather than in shorter-term or local climate data.

Climate regimes are patterns of climate behaviour that have been identified in different regions. They represent an important component of the description of climate in different parts of the world. Examples of these regimes are the Pacific North Atlantic Anomaly (PNA), the North Atlantic Oscillation (NAO) and the El Niño-Southern Oscillation (ENSO). The last of these is the best known and the most important; El Niño events are associated with extreme climate events such as floods and droughts in Africa, Australia, America and Asia. There seems no doubt that these regimes are influenced by increases in greenhouse gases; understanding the detail of these influences is an important topic of current research.

Question 3. Please explain the meaning of 'scientific consensus' and comment on the status of the science of climate change in the scientific and academic community.

Answer. Because discussion and debate are essential to the advancement of science, use of the expression 'scientific consensus' needs to be explained. In the context of the IPCC reports 'consensus' does not mean that agreement has been reached on all matters concerning climate change. What the IPCC has done in its reports is to distinguish between what is reasonably well known and understood from those areas where there is still much uncertainty and debate. What is often described as the IPCC 'consensus' (although the IPCC itself has never used that term) concerns matters such as the estimates of global average temperature rise (including its range of uncertainty), the range of estimates of sea level rise and the descriptions of likely dominant impacts in terms of precipitation and extremes—all under stated assumptions regarding future anthropogenic emissions.

The IPCC Reports have been given very strong support by many scientific bodies including most recently in a statement issued on the 7 June 2005 by the Academies of Science of the leading nations of the world (the G8 countries plus China, India and Brazil).

The science of climate change has grown very substantially over the last twenty years—so has the number of scientists working in the field. It has become an increasingly well established and respected academic discipline. Climate data has expanded a great deal and climate models have developed in size (thanks to increased computing power) and sophistication. Modeling of regional change is now developing rapidly into a useful and effective tool for the analysis and projection of regional changes. As the science has advanced, not only have the basic messages regarding climate change in the IPCC's 1990 and 1995 Reports been confirmed but the impacts then projected have proved, in general, to be too conservative.

Question 4. What is "abrupt climate change?" Can you identify any potential thresholds that might be crossed if insufficient action is taken to control CO_2 emissions? For example, I have heard that beyond certain temperature increases, large ice sheets could collapse, leading to huge increases in sea level. Can you comment on this and other potential thresholds?

Answer. The climate system is complex and highly non-linear in character. 'Abrupt climate change' refers to the possibility of unusual and rapid change occurring due to thresholds being reached or instabilities occurring. Some examples are:

1) If the average temperature in the vicinity of Greenland rises by more than about 3° C (5.5° F)—very likely to occur within the next 50 years—studies indicate that melt down of the Greenland ice sheet is likely to begin (*Climate Change 2001, the Scientific Basis* IPCC 2001 Report, chapter 11). Complete melt down, that could take 1000 years or more, would lead to 7m (23 ft.) of global sea level rise.

2) There is a lot of current concern regarding the stability of the West Antarctic Ice Sheet. It could lose mass over the next 1000 years with an associated sea level rise of several meters but there is incomplete understanding of some of the underlying processes (*Climate Change 2001: Synthesis Report*, IPCC 2001, Report Q4).

3) The long term stability of the ocean's Conveyor Belt (a circulation in the deep ocean coupling the oceans together) is also of concern. It is partially driven by the Thermohaline Circulation (THC) whose main source is the sinking of cold, dense water with high salinity at high latitudes in the Atlantic ocean. Increased precipitation at these latitudes and increased ice melt reduces the water's salinity, and hence its density, making it less likely to sink, so weakening the THC. All climate models that couple the ocean and atmospheric circulations show this weakening of the THC and hence also of the Gulf Stream. It is possible for the THC to be cut off completely—some models with 'business as usual' growth in CO_2 emissions show cut-off occurring within 100-300 years; there is also paleoclimatic evidence of it occurring in the past. If cut-off were to occur, the effect on the world's climate, especially in regions surrounding the north Atlantic, could be profound (*Climate Change 2001, the Scientific Basis* IPCC 2001 Report, chapters 7 and 9).

Question 5. Can you tell us something about the time horizon for stabilizing climate, given how long carbon dioxide remains in the atmosphere? Do we need to begin to control emissions now or can we wait?

Answer. There are three main time scales concerned with the stabilization of climate.

1) The first is the time response of the oceans to change. If emissions of greenhouse gases were to end immediately, the global average temperature would continue to rise at a similar rate as now for 30 to 50 years as the ocean's upper layers warm and then much more slowly over centuries as the lower layers of the ocean warm.

2) The second time scale is concerned with the life time of carbon dioxide in the atmosphere that is largely determined by exchange with the ocean. Its life time in the atmosphere is complex but is typically of the order of decades (for exchange with the ocean's upper layers) and centuries (for exchange with the

deeper ocean). If anthropogenic input of carbon dioxide to the atmosphere were to halt, its atmospheric concentration would only decline slowly.

3) The third time scale of importance is that applying to changes in anthropogenic emissions. Because of inertia in the system of energy infrastructure, changes in these emissions will take the order of decades to be realized.

For reasons associated with all these time scales—reducing the build up of further commitment to change associated with (1), recognizing the long time scale for emissions reductions to be reflected in the atmospheric carbon dioxide concentration with (2) and the time scales associated with energy infrastructure in (3)—there is an urgency to begin seriously to reduce emissions now.

Question 6. Given that there is still some uncertainty about the details of future warming, how should such uncertainty be dealt with in designing policy responses?

Answer. The need for appropriate policy responses despite scientific uncertainty was recognized 13 years ago in 1992 in the Framework Convention on Climate Change agreed by all nations at the Earth Summit in Rio de Janeiro, signed by President George Bush Senior for the United States and subsequently ratified unanimously by the U.S. Senate. In Article 3 it includes an agreement that the Parties to the Convention should "*take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost*."

Scientific certainty regarding many aspects of climate change has increased substantially since 1992 so that the need to take action is even stronger that it was then. A range of responses can be designed.

1) There are responses addressing energy efficiency e.g. in buildings, appliances, vehicles and in industry. Many of these will require regulation or incentives for them to be achieved on the scale required. Most of them are win-win in character, as most will lead to significant—even large—savings in cost or materials as well as in carbon emissions. There are numerous examples, for instance from U.S. industries, showing the value to the U.S. economy of such measures.

2) There are responses that also enhance energy security that are also win-win.

3) There are responses to do with adaptation to climate change, for instance to prepare, especially in the more vulnerable areas, for the expected increase in the number and intensity of extreme events (e.g. floods, droughts, heat waves). There is much evidence to show that more adequate preparation substantially reduces the damaging impacts of such events.

4) There are responses that would be much more cost-effective to take now rather than later, for instance in the design of power infrastructure with a typical life of 30-50 years. To have to replace such infrastructure before the end of its useful life would be costly.

5) There are technologies concerned with carbon-free energy sources (e.g. solar, biomass, biofuels, hydrogen technologies) that need to be developed as rapidly as possible to the level at which they can begin to act as significant alternatives to conventional fossil fuel energy sources.

Question 7. How do we know that emissions of carbon dioxide and other greenhouse gases are causing Earth's temperature to rise, as opposed to other factors that we have no control over; such as sun spots? Some assert that an increase in solar irradiance is the main cause of the Earth's current warming trend. Therefore, reducing fossil fuel emissions would not impact the Earth's temperature.

Answer. Measurements of solar irradiance have been made since 1979 from satellite mounted instruments. Small changes of up to 0.1% occur associated with the 11 year solar cycle. There is no evidence for changes greater than about 0.2% occurring in the longer term. Over the last 50 years, radiative forcing due to changes in solar irradiance is much smaller than that due to anthropogenic increases in greenhouse gases (*Climate Change 2001, the Scientific Basis* IPCC 2001 Report, chapter 6 and J. Hansen et al., *Earth's Energy Imbalance: Confirmation and Implications*, in Sciencexpress for 2 May 2005 doi:1110252).

Question 8a. There are some who question the veracity of the assertion that the earth has warmed substantially over the last century. Arguments typically fall into three categories. It would be useful if you would address each in turn:

Urban Heat Island Effect. This is the claim that the underlying temperature data is tainted by the proximity of data-generating thermometers to cities. As urban areas have grown over the last fifty years, the air temperatures around these cities have increased due to larger amounts of heat generating substances like rooftops and roadways. Scientists claim to have corrected for the urban heat island effect. How was this done, and how can we be sure that it was done correctly?

Answer. During development of the global surface temperature compilations, data from each observing station were quality-controlled. This included comparisons with neighbouring stations. Records showing complex inconsistencies relative to their neighbours were rejected from the analysis. This will have removed many urban stations where ongoing changes in the environment have caused multiple, non-climatic changes in the record. Where the neighbour-comparisons showed simpler inconsistencies such as a relative warming trend, the urban records were retained but were adjusted to be consistent with their rural neighbours (e.g. Hansen, J. et al., 2001, *J. Geophys. Res.*, 106, D20, 23,947-23,963).

There is substantial evidence that this procedure has been successful and that the land surface air temperature record used in assessment of climate change is not greatly influenced by urban warming. First, global rural temperature trends have been very similar to those based on the full network of stations (Peterson, T.C. et al., 1999, *Geophys. Res. Lett.* 26, 329-332). Secondly, ocean surface temperatures have risen nearly as much as those over land (Folland, C.K. & Karl, T.R. et al. 2001, chapter 2 in *Climate Change 2001: The Scientific Basis*. IPCC 2001 Report). A somewhat greater warming over land than over the ocean under increasing greenhouse gases is expected because of the greater thermal capacity of the oceans. Thirdly, temperatures on calm nights, when urban heat islands are mainly evident, show no more warming than temperatures on windy nights at a worldwide subset of the stations used to monitor global surface air temperature (Parker, D.E., 2004, *Nature*, 432, 290).

Uncertainties regarding urbanisation effects are allowed for in the global average surface temperature curve shown in the IPCC 2001 Report (*Climate Change 2001: The Scientific Basis*, Summary for Policymakers, Figure 1a). These uncertainties play a diminished role because land is only 30% of the global surface. Even the overall uncertainties, which include the effects of incomplete coverage and possible residual biases are much smaller than the global warming signal.

Question 8b. Satellite and Airborne Balloon Data Contradict Surface Temperature Readings. Global mean temperature at the earth's surface is estimated to have risen by about half a degree F over the last two decades. On the other hand, satellite measurements of radiances and airborne balloon observations indicate that the temperature of the lower to mid-troposphere (the atmospheric layer extending from the earth's surface up to about 8 km) has exhibited almost no change during this period. Please explain whether this discrepancy is, indeed, real and how to account for it.

Answer. Over the last few years, much careful and detailed study has been addressed to surface, balloon and satellite temperature observations taken over the last 25 years and the relationships between them. I summarize briefly in this answer the conclusions from a number of key papers that are now available describing this work, some of them published as recently as this August and two that will be published over the next two or three months. Because of the number of papers to which I am referring, for convenience I list all the references at the end of this answer. The main outcome of this work is that statements that the lower to mid-troposphere shows no warming trend or has cooled relative to the surface are no longer tenable. Such statements rely upon analyses of old radiosonde datasets, which had not adequately accounted for instrumental and observational biases, and a single satellite dataset. The first U.S. Climate Change Science Program report (*www.climatescience.gov*), which will be published in the late fall, is on this subject and will provide a far more detailed answer than is possible here.

Efforts in the last few years have led to significant revisions to existing upper-air temperature datasets and the production of a number of new balloon-based (Lanzante et al., 2003a, b, Thorne et al., 2005a) and satellite-based (Mears et al., 2003, Grody et al., 2004, Mears and Wentz, 2005) climate datasets under different, seemingly reasonable, approaches. An alternative approach to removing the stratospheric influence from the satellite records has also been proposed (Fu et al., 2004). Therefore the scientific community now have at their disposal a much larger number of independently derived estimates of tropospheric temperature change to analyse. Globally, the estimates of the average temperature trend for the period over which satellite data are available range from a slight warming to warming greater than that seen at the surface. It can be concluded therefore that the tropospheric data are consistent with a temperature trend similar to that at the surface, although the uncertainties are such that a relative cooling of the troposphere also cannot be ruled out.

Uncertainty in tropospheric trends is much greater than uncertainty in surface trends, reflecting the greater technological challenges of adequately monitoring changes aloft than at the surface. Only with the advent of recent datasets (see above) has the importance of structural uncertainty—the effects of methodological choices employed to identify and remove non-climatic influences from the raw data during dataset construction upon the climate dataset that results—become apparent (Thorne et al., 2005b).

Much of our uncertainty in temperature trends aloft arises in the tropics. Mears and Wentz (2005) have highlighted an error in the original satellite record of Christy et al. (2003) which led to a spurious cooling bias in the tropics. Balloon-based records are also sparsely located in the tropics, and have tended to launch only at local daytime (rather than twice-daily that is more common elsewhere). Day-time biases in radiosonde records are more pervasive due to solar-heating effects, and the lack of day and night launches at these stations potentially makes identification and removal of any non-climatic influences much harder (Lanzante et al., 2003a, Sherwood et al., 2005).

Santer et al., 2005 have recently compared tropical temperature predictions from 19 climate models run with historical changes in human-induced and natural forcing factors with four of the current observational datasets (2 balloon based, 2 satellite based). Within the tropics our expectations are that surface anomalies will be amplified aloft because of latent heat release upon condensation under a convective regime. All the models exhibit this behaviour on all timescales from monthly variability up to inter-decadal trends regardless of differences in model physics, resolution, and the forcings applied. The observations also exhibit amplification aloft on short timescales, but all except one dataset exhibits damping aloft on long timescales. Either in the real-world different processes dictate low-and high-frequency behaviour in the tropics and all the models fail to capture this, or, more plausibly, most observational datasets retain significant biases which impact their suitability for long-term trend analysis. Gaining unambiguous clarification of which is the case and gaining a cleaner estimate of recent tropospheric temperature changes in the tropics is seen as a high priority.

Question 8c. The Hockey Stick. In recent months, there have been assertions that the statistical method used to analyze global temperature data for the last several hundred years was biased towards generating the “hockey stick” shaped curve that shows sustained low and stable temperatures for hundreds of years with an extremely sharp rise in the last 100 years. Can you comment on whether the observations depicted in the hockey stick curve are, indeed, legitimate?

Answer. I have received a similar question from Senator Talent (Q6). I provide the same reply to both questions.

This is a fast moving area of research. Very recently the assertions by McIntyre and McKitrick (2005a, b) (MM), alluded to in the question (references at end of answer), have been shown by several papers to be largely false in the context of the actual data used by Mann and co-workers. Ammann (a palaeontologist at the National Centre for Atmospheric Research) and Wahl of Alfred University have two papers, one in review and one in press, that reproduce the original results published by Mann et al. in Nature in 1998 and Geophysical Research Letters, 1999 and prominently used in the IPCC Third Assessment Report. They demonstrate that the results of MM are due to MM having censored key proxy data from the original Mann et al. (1998) data set, and to having made errors in their implementation of the Mann et al. method. They specifically show that 15th century temperatures, related to the bristlecone pine issue, were not similar to 20th century temperatures, as was suggested by MM. Amman and Wahl issued a press release in May 2005 on this finding. Fuller details are at *http://www.ucar.edu/news/releases/2005/ammann.shtml* These authors state that they will make their full computer code available publicly.

A specific claim is made by MM that the “hockey stick” shape of the Mann et al. reconstructions is derived from the way Mann et al. normalise and centre their principal component pattern data. This has recently been tested. Rutherford et al. (in press, Journal of Climate) have shown that essentially the same result as Mann et al. is obtained using an entirely independent statistical method on similar data. This eliminates the step of representing regional tree-ring networks by principal components. The likely reason why Mann et al. were able to successfully use their particular technique is because the structure of paleoclimate data is more complex than the temporal “red noise” tested by MM.

Other investigators have reconstructed climate over the past 1000 years using very different techniques and different selections of data. Some of these results are recent, and some were shown in Fig 2.21 of the IPCC Third Assessment Science Report, Climate Change 2001. These authors tend to find a greater magnitude of climate variability than did the Mann et al. “hockey stick” results. In particular the “Little Ice age” centred around 1700 is generally cooler. Some of the more recent papers of this type show a Little Ice Age cooler by up to several tenths of a degree centigrade than any reconstruction shown in the Third Assessment Report in Fig 2.21, including that of Mann et al. However, all but one recent papers (Esper et al., 2002, Mann & Jones, 2003, Moberg et al., 2005, Huang, 2004, Jones & Mann, 2004, Bradley et al., 2003) find that the warmth of the late 20th century is still exceptional, as their reconstructions of the temperature level relative to the 20th century in the Medieval warm period are similar to the Mann et al. results. Soon & Baliunas concluded that the late 20th century was not unusually warm but their methodology was flawed (Mann and Jones, 2003) as they equated hydrological influences with temperature influences and assumed that regional warmth corresponded to hemispheric warmth.

I am sure that the IPCC Fourth Assessment Report will fully take all these new findings into account. In the meantime, it is important to recognise that no evidence has emerged that seriously calls into question findings regarding the climate of the 20th century and the influence of human activities as described in the IPCC 2001 Report.

Question 9. Some say that global warming might be a positive development? Will agricultural crop productivity improve due to the greater amount of CO_2 in the atmosphere, and can we expect the Arctic and Antarctic regions to become more habitable?

Answer.

ON CROP PRODUCTIVITY

Higher concentrations of CO_2 can enhance the productivity of crops that undergo C_3 photosynthesis (wheat, rice and most temperate crops) by fertilizing photosynthesis. In areas subject to water stress, productivity may also potentially be enhanced through higher CO_2 concentrations increasing the efficiency of water use. Crops with C_4 photosynthesis (maize, sorghum, millet, sugar cane) will not benefit from increased CO_2 in these ways.

These direct effects of CO_2 on crops should be viewed in the context of indirect effects due to the climate change arising from increasing CO_2. Crops are affected by changes in temperature and moisture availability. Warming in cold regions is expected to create generally more favourable conditions for crops, although the expansion of crop areas would be limited by soil quality and day length. In regions currently under agriculture, the specific types of crops which may be grown are expected to change with warming; C_4 crops may become more favoured in temperate regions. However, higher temperatures would be expected to lead to a greater requirement for irrigation due to increased water loss by evaporation. Warming may also increase the prevalence of some pests and diseases.

Moreover, changes in precipitation patterns could have major impacts. Some regions are predicted to become wetter and others drier. Wetter conditions in general would promote growth although increased severe heavy rainfall and floods would damage crops. Drier conditions in general would place greater demands on irrigation which itself would be subject to decreasing supply and competition from other uses such as drinking water and industry. Extreme high temperatures and droughts could have catastrophic impacts. In summary, some regions would expect net positive impacts whilst other would expect net negative impacts. Research on cereal yields assessed in the IPCC Third Assessment Report, which should be regarded as early work in an ongoing field of research, suggested that the greatest decreases in yield are expected in the tropics while some temperate and cold regions may see an increase in yield in the medium term.

It should also be noted that other changes in atmospheric chemistry related to climate change may affect crop yields. In particular, increases in ozone concentration are expected to be detrimental.

ON HABITABILITY OF THE ARCTIC AND ANTARCTIC

There may be an expansion of cropping regions towards/into the Arctic, although this would also be limited by other factors as described above. In general, the problems associated with extreme cold temperatures would be expected to decrease. New issues would arise with warming, such as ground subsidence due to permafrost melting. Antarctica is expected to remain ice covered for the next century and beyond.

Question 10. It is my understanding that the assessments of the progression of global warming through the next century and its impacts on changing the Earth's climate are largely based on computer modeling. It goes without saying that the planet's atmospheric, hydrologic, and meteorological systems are highly complicated.

What can you say about how climate modeling capabilities have advanced since scientists began evaluating the problem?

What is the level confidence that the computer models are providing useful projections of the future climate?

Answer.

HOW HAVE CLIMATE MODELING CAPABILITIES ADVANCED SINCE SCIENTISTS FIRST BEGAN EVALUATING THE PROBLEM?

Since the early days of modern climate modeling in the 1970s, scientists have progressively modeled more of the processes that play a role in climate. For example, early models represented only the atmosphere, with a very simple representation of ocean effects. Later the effects of changing ocean currents and ice were taken into account, and recently scientists have begun to model the interactions of climate with the biosphere. At the same time, our developing understanding of each system (atmosphere, ocean, etc.), together with increasing computer power, have meant that each component can be represented with greater realism.

As an example, today we are able to represent the circulations of the atmosphere and the ocean coupled together with sufficient realism that models reproduce many of the observed, large scale features of climate. Ten years ago this was only possible with the use of so-called 'flux adjustments' which corrected for the long term effects of slight errors in the models' heat distribution. Ten years before that we had not even begun to include the effects of ocean currents in models.

The ongoing development of models has led to increasing confidence in the modeling of many climate phenomena such as El Niño, monsoons, Arctic climate processes and the North Atlantic Oscillation.

Throughout this history of development, the models' prediction of a substantial global warming in response to increasing greenhouse gases has been consistent and unambiguous. As models improve we are able to add more detail and confidence.

WHAT IS THE LEVEL OF CONFIDENCE THAT THE COMPUTER MODELS ARE PROVIDING USEFUL PROJECTIONS OF FUTURE CLIMATE?

Confidence in model projections comes from three sources: the fact that they are based in fundamental physical principles such as conservation of energy, the fact that when driven by present day levels of solar energy input and concentrations of greenhouse gases and other trace species, they reproduce many observed features of present climate, and the fact that when driven by historical variations in those factors, they reproduce observed variations in climate. The development over the past 20 years of model formulation (discussed above) has seen a parallel increase in the veracity with which the models represent observed climate changes and variability.

The success of models in reproducing present and past climate lead us to believe that they are capturing much of the fundamental physics of the climate system. Hence the comprehensive climate models provide the best tool available to assess future climate change. Nonetheless there are quantitative differences between projections made with different models, and these differences represent a level of uncertainty in the modeling. By detailed analysis of the models, scientists can identify sources of uncertainty—for example the modeling of clouds continues to be an important issue—and by a painstaking process of research reduce that uncertainty over time. Models generally have greatest skill on larger scales, and as a generalization, the larger the scale (global, continental) the more robust are the modeling results.

Question 11. It is often asserted, by those who dispute the strength of the evidence of human-caused climate change, that the IPCC process has been politicized in a way that has tended to exaggerate the evidence for the reality of the problem and to understate the uncertainties. As the Chair of the IPCC's Working Group I on the science of climate change itself, could you characterize for us any political pressures you and your Working Group have experienced?

Answer. First, let me say that, as chair of Working Group I, a crucially important task for me was to ensure that any bias, agendas or pressures for political or other reasons (for instance personal agendas) were not allowed to get in the way of accurate, honest and balanced appraisal of the science.

During my years working with Working Group I, although I was supported in that task by the U.K. government, I played no part at all in the formulation or presentation of U.K. policy on climate change. The U.K. government made it clear that they expected me to avoid and refuse all political or other improper interference from whatever quarter in my IPCC work.

The occasions when political pressures were most apparent were the intergovernmental meetings when the Summaries for Policymakers (SPM) were discussed and approved. At these meetings, typically about 100 governments were represented and about 40 scientists representing the lead authors of the chapters were present to ensure the scientific integrity of the final document. The meetings were also open to representatives of non-governmental organizations from both the environmental and industry sides. The purpose of these meetings was to make sure that the SPMs were accurate and balanced scientifically and also that their presentations were clear, understandable and policy relevant.

The political pressures at these meetings that tended to be the most obvious and persistent came from a small group of oil producing states assisted by some of the industrial NGOs who worked to weaken or remove statements expressing the reality of climate change and its likely impacts. Less persistent pressures to strengthen such statements tended to come from some of the environmental NGOs and from a few country delegates. All proposals for change arising from these pressures were subjected to careful scientific scrutiny. After this thorough scrutiny (sometimes taking a substantial amount of time) the final text was accepted by all parties and all scientists without dissention—with one exception that occurred in 1995 when it became necessary to add a footnote expressing dissension by two countries, a footnote that was in fact withdrawn before the document's publication.

The final summary in each case was as accurate, balanced and unbiased as it was possible to make it. In every case, the SPM was improved in both accuracy and clarity by the process of the intergovernmental meeting. I can say categorically that there was no tendency to exaggerate evidence for the reality of the problem or to understate the uncertainties. If anything, the tendency was the other way—to be cautious in our statements and to make sure that we fully represented the uncertainties. The growth in the confidence expressed by the IPCC in its statements from the 1990 report through the 1995 report to the 2001 report, I believe, illustrates the IPCC's tendency to caution.

Question 12. In the 1970s, climate scientists claimed that the world was cooling and anthropogenic activities might be prematurely forcing the planet into an ice age. Today we hear that the earth is warming. What can you say about the scientific debate on cooling several decades ago and why is today's situation with global warming different?

Answer. There were some very cold winters in Europe and North America in the 1960s that led some scientists to speculate that we might be entering a new ice age. Most climate scientists disagreed with and indeed opposed that speculation—as I did—pointing out that there was nothing in the 1960s outside the range of natural variation. Also, according to the theory that ice ages are triggered by regular variations in the Earth's orbit that can be predicted precisely from astronomical data, the current interglacial period has tens of thousands of years to run before the appropriate conditions for the next ice age occur.

The current situation with global warming is very different. First, the basic physics of increasing surface temperature with increasing greenhouse gases has been known since the early 19th century. Secondly, the increase in global average temperature during the last 50 years is very unlikely to be due solely to natural variability. Thirdly, climate models that include the relevant physics and dynamics of the atmosphere's and ocean's structure and circulation are unable to simulate the profile of temperature increase unless the radiative forcing due to the anthropogenic increase of greenhouse gases is included in addition to all known natural forcings.

RESPONSES OF SIR JOHN HOUGHTON TO QUESTIONS FROM SENATOR BUNNING

Question 1. Would you say that the steps America has taken in the recent years to improve energy efficiency and produce lower carbon emissions from power generation are the right first steps in addressing climate change? Within that construct, given the current U.S. electricity supply that is more than 50% derived from coal, is encouraging clean coal technology, IGCC and carbon sequestration the most important immediate policy action we can take?

Answer. I agree that increasing energy efficiency across the board (e.g. in buildings, appliances, vehicles and in industry) is an essential part of action to address climate change. It has the advantage that most such actions are win-win in character i.e. they will lead to significant, even large, savings in cost or materials as well as in carbon emissions. There are numerous examples, for instance from U.S. industries, of the economic and other benefits of increased efficiency.

The other main action to address climate change mitigation is for the generation of energy to move as rapidly as possible to be less carbon intensive and eventually to be close to carbon free. It is clear that clean coal technology (IGCC and carbon sequestration) will play an important role in this future.

Question 2. Sir Houghton, you testified that over two thirds of the projected increase in emissions from now until 2030 will come from developing countries. Do you believe it would be responsible for EU countries and America to adopt an emissions reduction that failed to include this part of the world?

Answer. Countries who have joined the Kyoto Protocol have adopted emissions reductions that do not include developing countries. This is in line with the Framework Convention on Climate Change (FCCC) agreed by all nations in 1992 that states that industrialized nations that have already received large benefits from fossil fuel energy should be first to take action on climate change. But I agree that any international agreements post-Kyoto for emissions reductions need also to involve developing countries, especially those that are industrializing rapidly. I say a little more about this in my answer to Q3.

Question 3. You indicated in your testimony that America needs to take a global leadership position on climate change. You argued that developing nations will "follow, not lead" on the issue of climate change and that mandatory agreements with these nations would not be necessary as they voluntarily adopt emissions standards in the future. Yet the mandatory cap program recommended by the NCEP specifically discounts voluntary cap programs in America as unable to achieve necessary reductions. They have argued that without mandates, the marketplace will not make the adjustments needed to achieve the very aggressive goals envisioned. Do you believe it is consistent to advocate a "follow, not lead" voluntary approach with developing nations while dismissing the same approach in America?

Answer. Let me explain the arguments behind my use of the phrase 'follow, not lead' in respect of developing countries.

As I explained in my written testimony, we in the developed countries have already benefited over many generations from abundant and cheap fossil fuel energy—although without realizing the potential damage to the climate and especially the disproportionate adverse impacts falling on the poorer nations. The Framework Convention on Climate Change (FCCC) recognized the particular responsibilities this placed on developed countries to be the first to take action and to provide assistance (e.g. through appropriate finance and technology transfer) to developing countries for them to cope with the impacts and to develop cost effective sources of energy free of carbon emissions. This is at the basis of my 'follow, not lead' approach.

But it is not my intention to associate this approach only with voluntary action. Given the fact of first action taken by developed countries, for instance through the Kyoto Protocol, I agree that further action with mandatory targets and requirements are necessary for all countries. That is the urgent challenge of the next stage of negotiations that is taking place within the FCCC in which all countries—both developed and developing—must be involved.

Question 4. While you have presented what appears to be a united scientific front in the form of the statement from the academies of science from 11 countries, I am concerned by some of the news since the release of that statement. The Russian Academy of Sciences says it was misrepresented and that Russian scientists actually believe that the Kyoto Protocol was scientifically ungrounded. I am also aware that there was a significant misrepresentation on the science between our academy and the British representative.

Given this background, wouldn't you say there are still some pretty fundamental disagreements about the science of climate change among scientists around the world?

Answer. I have consulted the Royal Society in London about the questions you have raised about the joint statement from the academies and they have provided me with the information that follows in the rest of this answer.

All of the national academies that signed the joint statement on global climate change remain committed to it, and there is not, nor has there ever been, any disagreement between the signatories over its content.

There have been media reports that a member of the Russian Academy of Sciences, who is well-known for his opposition to the Kyoto Protocol, has requested that the Academy's President, Professor Yuri Osipov, should withdraw his signature from the joint statement. Professor Osipov has not done so.

There has been an exchange of correspondence between Dr. Bruce Alberts, the President of the National Academy of Sciences, and Lord May of Oxford, the President of the Royal Society, about a brief reference in the Society's media release accompanying the launch of the statement to an earlier report published by the NAS in 1992. The exchange of correspondence has not been about the content of the joint statement.

The signatories to the joint statement by the national academies remain committed to its content and hope that it will help the governments of the G8 nations to determine their future actions and policies on climate change.

Question 5. In this international academies statement, you find that an "immediate response that will, at a reasonable cost, prevent dangerous anthropogenic interference with the climate system," but continue to say in the following paragraph, "minimizing the amount of this carbon dioxide reaching the atmosphere presents a huge challenge." Could you please elaborate, since any response can't both be a "reasonable cost" and a "huge challenge" proposition, how you resolve the two?

Answer. The next paragraph in the academies statement goes on to say, *'There are many cost-effective technological options that could contribute to stabilizing greenhouse gas concentrations. These are at various stages of research and development. However barriers to their broad deployment still need to be overcome.'* The barriers that exist are not all economic ones. That this is the case is illustrated by the fact that it is generally agreed that many energy efficiency measures exist that could be implemented at no net cost or with significant cost savings—yet little action is taken about them. Other measures have been proposed that are described as win-win, implementation of which is not being pursued.

One of the barriers is the wide campaign of misinformation by vested interests that has persuaded people and their leaders to deny the existence of the problem of climate change or that even if the problem exists, little or no action about it need be taken at the moment.

An important part of the challenge, therefore, is first to ensure that governments, industries and the general public receive accurate and honest information that will give them the confidence to act, and secondly for governments in particular to set up the framework (including incentives and other appropriate economic measures) that will lead to action at reasonable cost. A further challenge in this process will be to carry out honest assessments of the 'reasonableness' of the costs of mitigation action by comparing them against the costs of inaction and the costs of adaptation, including so far as possible 'costs' that cannot be expressed in monetary terms.

Question 6. Several scientists have cited events like the high temperatures in Europe in the summer of 2003 and increased storminess in the 1980s and 1990s as evidence of climate change. Don't global ecosystems go through natural periods similar to these as well?

Answer. There is a great deal of variability in the natural climate system and extreme events occur—and always have occurred—on account of this natural variability. Because of this variability it is not possible, in general, to identify any particular extreme event as due to the increase of greenhouse gases through human activities. However, in mentioning the heat wave in Europe in 2003, in which over 20,000 people died, you cite the one recent event that is so very far outside the range of natural variability (the average temperature for the months of June, July and August in central Switzerland was 5 standard deviations away from the average since instrumental records began 140 years ago) that analysis shows that most of the risk of that event is almost certainly due to the increase in greenhouse gases (Stott, P.A. et al. 2004, *Nature* 427, 332-6). It therefore does provide evidence that human induced climate change is occurring.

Regarding the increased storminess of the 1980s and 1990s relative to the 1950s, this has been studied by insurance companies. They report an increase during this period in the number of weather of weather related disasters by a factor of 5 and in the economic cost (adjusted for inflation) of such disasters of a factor of 10. Although part of these observed upward trends is related to socio-economic factors (population growth, increased vulnerability and increased wealth) a substantial part is also linked to the increased frequency and intensity of such events (*Climate Change 2001: the Synthesis Report*, IPCC 2001).

This increased trend in the frequency and intensity of such events is what is expected in a world that is warming due to increased greenhouse gases. As I explained briefly in my written testimony, there are scientific reasons for this trend and further it appears as a robust result from climate models.

Question 7. There are a number of astrophysicists and other scientists who believe that sunspots are a major contributor to changing temperatures. A recent survey showed at least 100 such studies are underway. Why don't scientists put as much emphasis on this possibility or other aspects of natural climate variability as they do on emissions from human activity?

Answer. The IPCC in its reports has considered all aspects of natural variability as well as the effect of greenhouse gas emissions from human activity. A substantial section of chapter 6 of the IPCC 2001 Report, *Climate Change: the Scientific Basis* is devoted to possible solar influences on climate and about 50 papers on the subject are cited. It remains a subject of serious scientific research interest.

The IPCC's task, however, has been to compare all known natural influences on climate (including solar influences) with the effects of increasing greenhouse gases. Measurements of solar irradiance have been made since 1979 from satellite mounted instruments. Small changes of about 0.1% occur associated with the 11 year sunspot cycle. There is some evidence for solar influence on climate over the last few centuries, for instance during the first few decades of the 20th century. But the influence is small. Over the last 50 years, radiative forcing due to changes in solar irradiance is much smaller than that due to anthropogenic increases in greenhouse gases (see also J. Hansen et al., *Earth's Energy Imbalance: Confirmation and Implications*, in Sciencexpress for 2 May 2005, doi:1110252)

Question 8. Much of the discussion about climate science being settled is based on the summary chapter of the Intergovernmental Panel on Climate Change of the United Nations. The chapter made specific predictions about the pace of rising temperatures and the relative importance of human activities to climate change. And yet, the body of the report is much more ambiguous and inconclusive about the current state of the science. Is anything being done to ensure that the summary of the next IPCC report is more reflective of the overall analysis by the scientists?

Answer. I am aware that statements are often made and quoted asserting that the Summaries for Policymakers (SPM) of the IPCC reports do not accurately reflect the science of the underlying chapters. Yet, to my knowledge, none of those expressing such views have provided evidence or examples to support them.

It is important to recognize the IPCC's purpose in preparing an SPM for its reports. As an intergovernmental body, the IPCC is bound to produce its conclusions succinctly and in a form that is understandable by policymakers and relevant and helpful to their needs. The SPM therefore is not a scientific summary of all the science laid out in the chapters. It does not list, for instance, all the factors or all the arguments involved in the scientific appraisal of any given area. Each chapter, in any case, produces its own scientific summary. The SPM is a summary of conclusions, largely taken from the chapter summaries, selected for their policy relevance and in the drafting of which lead authors from the chapters have played a full part.

It is also important, as your question implies, that the SPM adequately expresses the degree of certainty to be associated with any conclusion. The IPCC has spent a lot of time debating how this can best be done and a large proportion of the time in the intergovernmental meetings that have approved the SPMs (see also my answer to Q11 asked by Senator Bingaman) has been taken up with ensuring that the final SPM text accurately reflects the chapters in the degree of confidence expressed in the conclusions. When this has to be done succinctly, as the SPM requires, it is helpful for confidence to be expressed quantitatively. For instance, in all the IPCC scientific reports, so far as possible, numerical values quoted in the conclusions also included error bars to express their uncertainty. In addition, in the 2001 IPCC Report, many of the more qualitative statements have been made quantitative by attaching to them numerical estimates of probability. For instance, a given conclusion described as *likely* is estimated to have a probability of being true in the range 67% to 90% and as *very likely* when its probability of being true is estimated as in the range 90% to 99%, and so on. In this way, uncertainties have been presented in a manner that can be more easily interpreted and used by policymakers, especially when the impacts of climate change have to be folded into the consideration of wider policy issues involving future energy generation or the provision of security.

Further, in the IPCC 2001 SPM, clearly listed are areas of importance where there is no evidence of change, for instance in sea ice cover in the Antarctic or in the average number and intensity of tropical cyclones over the 20th century.

I have no doubt at all that matters regarding the accuracy and balance of the SPM and the way uncertainties are represented continue to be very fully discussed within the IPCC as it prepares the Fourth Assessment Report.

Question 9. The natural "greenhouse effect" has been known for nearly two hundred years and is essential to the provision of our current climate. There is significant research in the literature today that indicates humans, since the beginning of their existence, have caused an increase in the greenhouse effect. Some argue that the development of agriculture 6,000 to 8,000 years ago has helped to forestall the next ice age. The development of cities, thinning of forests, population growth, and most recently the burning of fossil fuels, have all had an impact on climate change. Our ecosystems have constantly adapted to change, as we as humans have adapted to our ecosystems as well. Is it possible that the increased presence of CO_2 caused by the 8,000 years of modern human existence may be something our ecosystems will continue, as they previously have, to naturally adapt to?

Answer. According to data from the Vostok and Taylor Dome ice cores, atmospheric CO_2 concentration rose by 20ppm (from 260ppm to 280ppm) between 8,000 years ago and the start of the industrial era (circa 1750). Since then, CO_2 has risen to 377ppm in the Mauna Loa record. This is higher than at any time in the 440,000 year ice core record and also higher than at any time in the last 20 million years according to geochemical evidence. There are therefore no examples in the recent past to which we can refer for evidence of adaptation to current or projected future CO_2 levels.

The amount of the CO_2 rise over the last 250 years has been nearly 5 times that seen over the previous 8,000 years, with the rate of rise 150 times faster. Ecosystems will already need to be adapting more rapidly than before. In the six illustrative SRES scenarios examined in the IPCC Third Assessment Report of 2001, the CO_2 concentration reaches between 540ppm and 970ppm over the next 100 years. These correspond to rates of rise of 650 to 2300 times faster than over the 8,000 years pre-industrial. Adapting to the associated climate change under any of these scenarios will become increasingly difficult for both ecosystems and humans.

Question 10. The panel touched on some energy alternatives such as biomass, natural gas, and nuclear power, yet there was little mention of hydrogen power. From a scientific viewpoint, where do you think we are on being able to really utilize hydrogen power? What is the potential of hydrogen power?

Answer. Hydrogen has many advantages as a fuel in that it is very non-polluting and is ideal for using in fuel cells that are potentially highly efficient and convenient devices for producing electricity. Further, providing the hydrogen is produced from a carbon-free source, it does not add to the greenhouse effect.

Hydrogen power does not, however, exist in isolation from the means by which the hydrogen is produced. That may be from solar energy or from the energy alternatives that you have mentioned such as biomass, natural gas or nuclear sources. Hydrogen essentially provides a secondary rather than a primary source of energy.

There seems to be general recognition that hydrogen has great potential and will become an important and probably dominant fuel in the future. Before this occurs on a very large scale, substantial further development of fuel cells and of technologies for hydrogen storage are required especially for use in vehicles.

Question 11. The panel established very clearly that we should adopt policies that decrease carbon emissions regardless of any other carbon emissions policies we pursue. We are currently or will shortly be providing expanded incentives for clean coal, nuclear energy and renewable fuels. Do you feel this is money well spent? What technologies do you feel the government should be more involved in developing?

Answer. I am not an expert on energy policy so can only make a general comment. It is clear, I believe, that there is no one solution to the challenge of moving to carbon free energy, so all possibilities need to be explored and assessed. There are also comparatively new technologies, especially some in the field of renewables, that will require considerable government support before they can become commercially competitive.

RESPONSES OF SIR JOHN HOUGHTON TO QUESTIONS FROM SENATOR TALENT

Question 1. There has been a fair amount of criticism of the output of the models used to forecast possible climate conditions in the future, due in part to the data assumptions made. How responsive has the IPCC been to external criticism? Has this criticism led to any modeling or data input revisions, and what was the result of these revisions?

Answer. In contrast to models of the economy, for example, climate models are not based on empirical or statistical extrapolation but they possess a sound theoretical basis in the established laws of physics and dynamics. These include the laws of conservation of mass, heat, moisture and momentum and the equation of state. Future projections are determined through integration of the equations describing these laws together with Newton's equations of motion. Such models are essential tools for adding together all the non linear processes involved in the behaviour of the total climate system. A good description of the present state of climate modeling can be found in J.F.B.Mitchell, Can we believe predictions of climate change? ***Q.J.R.Meteorol.Soc.***, 130, 2341-2360, 2004.

There has been enormous development in the size, sophistication and skill of climate models over the last 30 years. The global modeling community has been closely involved in the IPCC process and contributed a great deal to it. In particular, for the 2001 IPCC Report, 20 groups in different institutions and countries running over 30 general circulation models with full coupling between the atmospheric and ocean circulations set up elaborate procedures to evaluate and compare formulations and results between all 30 models. This process has been highly productive in leading to improvements in model performance, creating increasing confidence in model results and providing guidance for model developments.

Many of the criticisms of models commonly voiced concern older models in some of which adjustments (e.g. flux adjustments at the atmosphere-ocean boundary) had to be made the validity of which was questioned. The modeling community has worked to remove such limitations. For instance, modern models do not require flux adjustments. The main uncertainties in models that remain arise from difficulties of adequately dealing with clouds and with the ways in which small scale motions (too small for discrete model description) influence motions on the larger scale. Uncertainty about clouds is the main reason for the range of uncertainty from 1.5 to 4.5° C still quoted by the IPCC for the climate sensitivity (the increase in equilibrium surface temperature arising from a doubling of carbon dioxide).

Question 2. You say in your written testimony (p. 7) that the Kyoto Protocol is just a "beginning for the process of reduction" for countries that ratified the protocol. What level of cuts are necessary to reach the goal of Kyoto? If the EU is having trouble meeting the "beginning" targets, how will they meet the necessary targets without wrecking their economies, and how are the rising emissions of developing countries factored in?

Answer. I have consulted with the U.K. government in providing this answer. The goal of the Climate Convention is to stabilise greenhouse gases in the atmosphere at levels which avoid dangerous anthropogenic climate change. The European Union (EU) has suggested that this would mean avoiding temperature rises greater than 2 degrees Celsius above pre-industrial levels. Recent research indicates that to do so requires global greenhouse gas emissions to peak within the next two decades, followed by substantial global reductions relative to 1990. These would need to be of the order of at least 15% and perhaps as much as 50% by 2050. Developed countries would need to take greater action which suggests that their emissions will need to fall by between 60 and 80% of current levels by 2050. Kyoto is thus clearly just a first step as its goal is to achieve reductions in developed country emissions in the near term (2008 to 2012). However the Protocol includes built in mechanisms for considering what actions should be taken by parties in the period after 2012 and initial discussions on this are due to begin among Kyoto parties at the 1st meeting of the Parties to the Kyoto Protocol, this November in Montreal.

With regard to the EU's Kyoto targets, a recent European Commission report (*http://europa.eu.int/eur-lex/lex/LexUriServ/site/en/com/2004/com2004*_0818en01.pdf) suggests that a combination of existing domestic policies and measures, additional policies and measures which are already in an advanced state of planning, and emission credits gained through the Kyoto Protocol's project-based mechanisms will deliver a total EU-15 emissions cut of 8.6% by 2010 (the EU-15 target is −8%). The EU Council of Ministers has set out a range of emission reduction pathways, as noted above, to consider when discussing the future with other parties. The U.K. aims to use its Presidency of the EU to launch the process of developing strategies or pathways to deliver those kinds of medium and long term targets. The U.K. hopes to introduce in the EU the same kind of process taken by the U.K. in 2003 when it formulated its Energy White Paper, undertaking the necessary work to demonstrate that future targets adopted are achievable and compatible with healthy economic growth.

Question 3. You note in your written testimony (p. 8) that for the U.K. to meet its target of 60% reductions by 2050, it would suffer a loss of 6 months' growth over 50 years, or 1% of the growth over that time period. How much money in GDP and how many lost jobs does that represent? Does this result in any reduction in emissions, particularly in light of the fact, as you note, that China is building the equivalent of a 1 gigawatt, fossil-fuel powered generating station every week?

Answer. I have consulted with the U.K. government in providing this answer. Analysis for the U.K.'s Energy White Paper in 2003 concluded that the costs of achieving a 60% reduction in CO_2 emissions might be around 0.5-1% of GDP in 2050. This would be broadly equivalent to a reduction of about 0.01 percentage points a year in the assumed GDP growth rate of 2.25% a year. The cost to GDP in 2050 is estimated to be between £10bn and £25bn per annum (in 2000 prices) by 2050 compared with a forecast level of GDP in 2050 of around £2500bn. There are no figures available for the effect on employment. If the U.K. achieves a 60% reduction in its carbon dioxide emissions this would mean that the U.K.'s annual emissions had fallen to around 65 million tonnes of carbon by 2050, about 90 million tonnes lower than they are currently. To put this in context, a new 1 GW coal-fired power station might be expected to emit around 1.5 million tonnes of carbon per year. The Energy White Paper recognises that it won't be enough for the U.K. to act alone and that others will need to make comparable efforts to meet the challenge of climate change.

Question 4. The time for greenhouse gas emissions in the atmosphere to decay, as predicted by the IGCC model is about 37 months. However, actual experience based on studies of volcano eruptions suggest a decay time of half of that (Michaels and Knappenberger, 2000) or less (Douglass and Knox, Univ. of Rochester, reported in *Geophysical Research Letters*), meaning a lower climate sensitivity and lower the future temperature rise. Have the IGCC numbers been rerun to account for this actual data, rather than sticking to the modeling assumptions?

Answer. Different greenhouse gases have different lifetimes in the atmosphere. The fundamentals of their atmospheric cycles and lifetimes are well understood. I do not recognize to what decay the 37 months refers. However, I believe the Senator's question is rather about the transient climate response observed after the Pinatubo volcanic eruption and how this might be used to constrain our knowledge of climate sensitivity and "global warming commitment" (the extra-warming in the pipeline once greenhouse gas concentrations have been stabilized). The climate response to stratospheric aerosols induced by the Pinatubo eruption has been used in a number of studies to attempt to provide information about climate sensitivity or the time constant of climate response to perturbations in radiative forcing such as occurs with greenhouse gases. The one you cite by Douglass and Knox essentially employs an extremely simplistic one-dimensional model that includes no allowance for the ocean and also employs an incorrect definition of radiative forcing. Other studies have used full three-dimensional climate models (Kircher et al., Journal of Geophysical Research, 104, 19039-19055, 1999; Soden et al., Science, 296, 727-730, 2002) and find that moderate to high climate sensitivities (i.e. 3 to 4.5 degrees C for a doubling of CO_2 at equilibrium) are compatible with the observations. However, as pointed out by R.S. Lindzen and C. Giannitsis (J. Geophys. Res., 103, 5929-5941, 1998) in a detailed study on the climatic effects of volcanic cooling, the uncertainties associated with the climate response are such that no clear conclusions can be drawn regarding either climate sensitivity or the time scale of climate response from studies on a single volcanic eruption such as Pinatubo.

Question 5. What has been the pattern of findings as the science improves—more or less climate sensitivity to carbon concentration in the atmosphere, greater or lesser projected warming? E.g., I understand that the large majority of models predict a more modest warming of 2-5 degrees F, as opposed to IGCC's Third Assessment Report which predicts about 11 degrees F (6 degrees C) by 2100.

Answer. The IPCC's Third Assessment Report in fact gave an uncertainty range of 1.4 to 5.8 degrees C (2.5 to 10.5° F) for the projected global average temperature rise in 2100—you just mention the top end of that range. Included in that range are uncertainties in projections of how greenhouse gases will increase in the 21st century (that is dependent on how emissions due to human activities evolve) in addition to uncertainties in our scientific understanding of the response of climate to increased greenhouse gases. The range for global average temperature rise projected for 2100 published in the IPCC 1995 Report of 1.0 to 3.5° C (1.8 to 6.3° F) was less than that in 2001, largely because of different assumptions about likely emissions of aerosols due to human activities and also of greenhouse gases, in the 21st century.

The response of climate to increased greenhouse gases is described by a quantity called the climate sensitivity that is defined as the amount of global average temperature increase for a doubling of atmospheric carbon dioxide concentration under equilibrium conditions. This is a quantity determined from the science. Your question, I believe, is asking how estimates of the climate sensitivity have changed as our understanding of the science has improved.

In both the First and Second IPCC assessment reports of 1990 and 1995, the range of estimates of climate sensitivity was 1.5 to 4.5° C (2.7 to 8.1° F). In the IPCC Third Assessment Report (TAR) of 2001, the conclusion drawn in the summary section of chapter 9 was that "the previous estimated range for this quantity, widely cited as +1.5 to +4.5° C, still encompasses the more recent model sensitivity results". However, in Table 9.4 of that chapter, the range of values of climate sensitivity in the 15 full climate models available to that chapter was quoted as from 2.0 to 5.1° C (3.6 to 9.2° F) with a mean of 3.5° C (6.3° F), indicating a tendency for models at that time to show somewhat higher values of climate sensitivity. Since the publication of the TAR there have been a number of studies in which models have produced climate sensitivities in excess of 6° C (11° F) (e.g. Murphy et al., 2004, Nature, 430, 768-772; Stainforth et al., 2005, *Nature*, 433, 403-406). In general, the lower end of the uncertainty range for climate sensitivity has tended to remain at 1.5-2° C (2.7-3.6° F) while the upper range has increased.

In conclusion, therefore, as the science has developed and improved, there has been a tendency for an increase in the likelihood of greater sensitivity and greater warming.

Question 6. What's the status of the review of the Mann "hockey stick" temperature curve? I understand that studies by Stephen McIntyre and Ross McKitrick suggest that it relied on the statistically insignificant bristlecone pine. Is the IPCC taking another look at that work, which forms the basis for much of today's climate change debate?

Answer. I have received a similar question from Senator Bingaman (Q8c). I provide the same reply to both questions

This is a fast moving area of research. Very recently the assertions by McIntyre and McKitrick (2005a, b) (MM), alluded to in the question (references at end of answer), have been shown by several papers to be largely false in the context of the actual data used by Mann and co-workers. Ammann (a palaeontologist at the National Centre for Atmospheric Research) and Wahl of Alfred University have two papers, one in review and one in press, that reproduce the original results published by Mann et al. in Nature in 1998 and Geophysical Research Letters, 1999 and prominently used in the IPCC Third Assessment Report. They demonstrate that the results of MM are due to MM having censored key proxy data from the original Mann et al. (1998) data set, and to having made errors in their implementation of the Mann et al. method. They specifically show that 15th century temperatures, related to the bristlecone pine issue, were not similar to 20th century temperatures, as was suggested by MM. Amman and Wahl issued a press release in May 2005 on this finding. Fuller details are at ***http://www.ucar.edu/news/releases/2005/ammann.shtml***. These authors state that they will make their full computer code available publicly.

A specific claim is made by MM that the "hockey stick" shape of the Mann et al. reconstructions is derived from the way Mann et al. normalise and centre their principal component pattern data. This has recently been tested. Rutherford et al. (in press, Journal of Climate) have shown that essentially the same result as Mann et al. is obtained using an entirely independent statistical method on similar data. This eliminates the step of representing regional tree-ring networks by principal components. The likely reason why Mann et al. were able to successfully use their particular technique is because the structure of paleoclimate data is more complex than the temporal "red noise" tested by MM.

Other investigators have reconstructed climate over the past 1000 years using very different techniques and different selections of data. Some of these results are recent, and some were shown in Fig 2.21 of the IPCC Third Assessment Science Report, Climate Change 2001. These authors tend to find a greater magnitude of climate variability than did the Mann et al. "hockey stick" results. In particular the "Little Ice age" centred around 1700 is generally cooler. Some of the more recent papers of this type show a Little Ice Age cooler by up to several tenths of a degree centigrade than any reconstruction shown in the Third Assessment Report in Fig 2.21, including that of Mann et al. However, all but one recent papers (Esper et al., 2002, Mann & Jones, 2003, Moberg et al., 2005, Huang, 2004, Jones & Mann, 2004, Bradley et al., 2003) find that the warmth of the late 20th century is still exceptional, as their reconstructions of the temperature level relative to the 20th century in the Medieval warm period are similar to the Mann et al. results. Soon & Baliunas concluded that the late 20th century was not unusually warm but their methodology was flawed (Mann and Jones, 2003) as they equated hydrological influences with temperature influences and assumed that regional warmth corresponded to hemispheric warmth.

I am sure that the IPCC Fourth Assessment Report will fully take all these new findings into account. In the meantime, it is important to recognise that no evidence has emerged that seriously calls into question findings regarding the climate of the 20th century and the influence of human activities as described in the IPCC 2001 Report.

Question 7. If all the countries that have signed Kyoto stay within compliance of Kyoto, how much of a reduction in global warming would this result in?

Answer. I have consulted with the U.K. government in providing this answer. If the developed country parties make the reductions they have committed to, in the period 2008-2012 the reduction in projected global emissions will be up to about 2%. This takes account of the fact that developing country emissions will still rise as they do not have emission reduction targets, although mechanisms such as the clean development mechanism, together with technology transfer and capacity building, will be expected to lead to some reduction in their emissions growth. The significance of the first commitment period is as a first step for building broader coalitions and a longer-term engagement aimed at reducing global emissions of greenhouse gases, as well as the establishment of essential monitoring and measuring standards and cost-effective market mechanisms such as international emissions trading.

Question 8. Can you confirm that suspended water vapor levels, cloud cover percentages and direct solar irradiation changes over time all represent variables in these forecasting models that could have significant impacts on the conclusions of the results of these models?

Answer. In the formulation of climate models, estimates of direct solar radiation changes with time are included, along with estimates of all other known forcing factors, both natural and anthropogenie. There are periods such as that from around 1900-1940 when it is believed solar radiation changes had a significant effect. Any effect of solar radiation changes over the last 50 years, however, has been small compared with the effects of increasing anthropogenic greenhouse gas emissions *Climate Change; the Scientific Basis*, the IPCC 2001 Report, chapter 6).

Water vapor concentration and the coverage of cloud (at different levels and of different types) are variables within the model equations that are generated within the model as the model integrations progress by applying the physical laws on which the model depends. These variables are not introduced from outside except in the specification of initial conditions; the influence of the these is soon lost as the integrations progress. The way in which clouds are treated within the model equations differs significantly amongst models. The largest single uncertainty in model results arises from uncertainties regarding this treatment as is explained in Climate Change; the Scientific Basis, the IPCC 2001 Report, chapter 8.

Question 9. In looking at pre-industrial global temperature patterns, would you agree that changes in temperatures over time have occurred that had no anthropogenic basis?

Answer. Temperature is a climate variable that has large natural variability over all time scales and space scales. The natural variability can arise because of external forcing such as changes in solar radiation or because of variations within the climate system itself. In addition to this natural variability, changes occur because of human activities, for instance deforestation, changes in vegetation or land use and since the industrial revolution because of changes in atmospheric composition especially most recently emissions into the atmosphere of growing quantities of greenhouse gases.

The task of the IPCC has been to study thoroughly all reasons for climate variability and change both natural and anthropogenic and, through appropriate scientific analysis and the employment of climate models, to distinguish as far as possible between natural and anthropogenic effects.

Question 10. Do we know what the "best" global temperature is to sustain life?

Answer. Life of all kinds—human and non human—exists successfully on earth under a very wide variety of climates. What is important to realize is that humans and ecosystems have over millennia and centuries adapted to reasonably stable local climatic conditions. But unusually large climate changes are beginning to occur on a global scale and at a rate that is greater than for at least 10,000 years. If the local climate changes too rapidly, adaptation to new conditions may be difficult for both ecosystems and humans. The IPCC has concluded, *'Projected climate change will have beneficial and adverse effects on both environmental and socio-economic systems, but the larger the changes and rate of change in climate, the more the adverse effects predominate'* (Climate Change 2001, Synthesis Report,

Many ecosystems are sensitive to unusual and sustained changes in temperature or precipitation. I give two examples. First, many areas of tropical corals are suffering 'bleaching' because of increases in ocean temperature. Corals are also expected to be seriously affected by the increased ocean acidity that is occurring because of carbon dioxide from anthropogenic sources that is emitted into the atmosphere and then dissolved in ocean waters—an environmental problem that has only recently been appreciated. (see U.K. Royal Society Report 12/05, *Ocean acidification due to increasing atmospheric carbon dioxide*, 30 June 2005, available on <*www.royalsoc.ac.uk*>). A second example is of substantial die back that is occurring in forests at northern high latitudes because of increased warming outside their normal range of tolerance.

Over past epochs humans have responded to severe local or regional climate changes by moving into other more tolerable areas. In our modern extremely crowded world large population movements are no longer possible. To some adverse changes, it will be possible for humans to adapt, although often at significant cost. For instance, adaptation to changes in average water availability, average temperatures or some sea level rise might be achieved through alterations to water resource infrastructure, building design or sea defences. For many low lying areas, however, such as large populated deltas or many islands, adaptation to sea level rise is not a practical possibility and many millions will be displaced. Further, the increases that are likely in the frequency and intensity of floods and droughts will cause large problems especially for populations in sub tropical countries that are particularly vulnerable to such events.

Question 11. What is currently being done to curb emissions from parts of the world in poverty who are deforesting their environment and burning biomass for all means of day-to-day living, and are these emissions continuing to increase in the world?

Answer.

ARE THESE EMISSIONS CONTINUING TO INCREASE

Deforestation releases CO_2 to the atmosphere both from the vegetation directly and also by disturbing the soil. The numbers quoted below refer to this. Burning biomass as a day-to-day fuel leads to net CO_2 emissions if the biomass is not replaced. If the biomass is grown explicitly for fuel wood then there are no net CO_2 emissions as the carbon biomass stock on average remains constant.

CO_2 flux from land-use change is increasing at about the same rate as fossil fuel usage. On a global scale, in 1980 land-use change accounted for about 23% of total anthropogenic emissions and in 2000 about 24%. Regionally, there are some differences. From 1980 to 2000, land-use carbon fluxes increased by 30% in tropical America—close to the global average increase. Larger increases occurred in tropical Asia (56%) and tropical Africa (60%).

(Data taken from: Houghton, R.A., and J.L. Hackler, 2002. *Carbon Flux to the Atmosphere from Land-Use Changes*; and Marland, G. et al., 2005, *Global, Regional, and National CO_2 Emissions*—both in Trends: A Compendium of Data on Global Change, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. Both are available at: <*http://cdiac.esd.ornl.gov/trends/trends.htm*>.)

WHAT IS CURRENTLY BEING DONE

My main personal experience of this problem comes through the Shell Foundation (a large charity set up by the Shell Company mainly to support sustainable energy provision in the third world) of which I am a Trustee. The Foundation has a large program aimed at the creation of local enterprises that build and market simple efficient stoves using traditional fuels that will substantially the reduce the amount of fuel that is used and also reduce indoor air pollution with the serious damage to health that it causes. The Foundation also has programs aimed at the creation of enterprises to provide sustainable and affordable energy to poor communities often from the use of readily available waste material (e.g. rice straw in China, coconut shells in the Philippines, etc.). The potential for the multiplication of such projects is very large. An aim of the Foundation is to join with other bodies and agencies to create mechanisms for the large scale-up of such programs so that they can become significant on a global scale both in the provision of energy to poor communities and also in reducing greenhouse gas emissions.

Question 12. Do you believe it is practical to seek emission controls in parts of the world that are struggling in poverty?

Answer. I believe the top priority is to achieve emissions reductions in the parts of the world that are making the largest emissions contributions i.e. the industrialized nations and those nations that are rapidly industrializing. Regarding nations 'struggling in poverty', as you will see from my answer to Q11, I believe there is great opportunity for agencies and governments in the developed world to assist them to move out of poverty in ways that are sustainable and that reduce rather than increase their greenhouse gas emissions.

Question 13. What is being done to curb emissions in the developing countries like China and India?

Answer. In reply to Question 3 from Senator Bunning, I emphasized the importance of developed countries leading by example with regard to developing countries such as China and India. I also mentioned the responsibility on developed countries to develop partnerships with countries that are seeking to industrialize so as to assist them in whatever ways they can with the development of low carbon or carbon free energy generation. Further, it is essential that developing countries are full participants in agreements that need to be reached regarding targets and mechanisms in the next stage of negotiations that is taking place within the FCCC.

RESPONSES OF SIR JOHN HOUGHTON TO QUESTIONS FROM SENATOR FEINSTEIN

Question 1. Is there any credible scenario for stabilizing greenhouse gas emissions that does not involve the United States and other major emitters stopping their emissions growth over the next couple of decades and sharply reversing their emissions growth by 2050.

Answer. All scenarios of global emissions that stabilize carbon dioxide concentrations in the atmosphere this century slow emissions growth over the next few decades and reverse that growth severely during the second half of the century. That applied to *global* emissions. The slowing and reversal of emissions for industrialized countries need to occur more quickly than for global emissions so as to allow room for growing industrialization in developing countries. I provide examples of stabilization profiles for both developed and developing countries in my written testimony to the committee.

Question 2. Would the National Commission on Energy Policy's proposal stop and then reverse U.S. greenhouse gas emissions?

Answer. I am not an expert of energy policy and cannot comment in detail on the proposals of the National Commission on Energy Policy. As I understand it, their main proposals are limited to stopping the growth of emissions by 2020 and do not cover the period after that date, although they recognize in their report the need for the reversal of emissions growth after 2020.

RESPONSES OF DR. MARIO MOLINA TO QUESTIONS FROM SENATOR BINGAMAN

Question 1. Over the last several decades, anthropogenic emissions have "substantially contributed" to the increase in average global temperatures. Upon receiving a question from one of the Senators, one of the panelists suggested that "80 percent" of the warming was due to human activities. Do all the panelists agree? Please provide information as to how this estimate was derived.

Answer. Other panelists will need to answer for themselves as to whether they agree with the 80 percent figure. While I personally believe that estimate is probably in the right ballpark, I think it's less important to focus on a particular number than it is to stress the broader scientific consensus reflected in recent findings of the Intergovernmental Panel on Climate Change (IPCC)—in particular the IPCC's finding that "MOST of the warming of the past 50 years is attributable to human activities."

As for the techniques used to estimate the extent of human vs. natural influences on climate, estimates such as the one noted above are generally based on a careful statistical comparison of the temperature record over the past century against the timing and estimated magnitudes of the positive and negative "forcings" (warming and cooling influences respectively) known to have been produced in this period by both human and natural phenomena. Examples of such forcings include volcanic eruptions (which are thought to have had a slight overall cooling influence on surface air temperatures over the past 50 years), solar changes (which are not thought to have had a significant effect over this time period but may account for a slight amount of warming), emissions of sulfates and other aerosols (some of which would have had a cooling effect), and emissions of carbon dioxide, methane, and other greenhouse gases (which would have a strong warming effect).

A crucial test of our confidence in the proposition that human activities are having a substantial impact on global climate is that when the best current climate models are supplied with the estimated time history of all known forcings—natural and human—as inputs, the temperature history for the 20th century calculated by the models matches the observed temperature record. If the "model" climate is driven only by the known natural forcings, the match with observations is poor; that is, the natural forcings cannot account, by themselves, for a large part of the changes in temperature that have been observed.

Question 2. We received testimony that sought to distinguish between average global temperature changes causes primarily by anthropogenic emissions and local/regional temperature changes caused at times by natural variation. Please explain in greater detail.

Answer. The surface temperature of the Earth is never uniform. The average temperature that features in discussions of climate change represents an average over every place on Earth, including some places that are warmer than average and some that are cooler. (The average is also an average over time—over the 24 hours in each day and the 365 days in each year, if one is speaking, say, of the average temperature for 1850 or 2000 or 2005.) *Changes* in temperature are likewise not uniform spatially or temporally, and this is true whether the changes result from human or natural forces.

For example, volcanic eruptions reduce the average temperature of the Earth for a time because the fine particles they inject into the stratosphere reflect sunlight back into space before it reaches Earth's surface. The cooling they cause is not, however, spatially uniform because the particles are most concentrated in the latitude band where the eruption has occurred. (The winds that spread these particles around blow mostly from west to east moving them quite rapidly along lines of constant latitude while spreading them only slowly to the north and south.) In addition, the cooling effect declines over time because the particles eventually settle back to Earth.

Particles added to the atmosphere by human activities—including especially agricultural burning, fossil-fuel burning, and human-caused forest fires—also show the highest concentrations, and therefore the largest effects, in the latitudes where they are emitted. Some of these particles tend to cool the Earth below them, like those from volcanic eruptions, while others (such as black soot from incomplete combustion) tend to warm the Earth below.

Unlike particles from volcanic eruptions, most of the greenhouse gases being added to the atmosphere by human activities stay there long enough to become uniformly mixed through the atmosphere around the globe. But still, the temperature changes that result from these greenhouse-gas increases are not uniform over the surface of the Earth, because the other forces that shape the surface temperature at any given place can act to either amplify or reduce the impact of altered greenhouse-gas concentrations on local temperatures. Such forces can include natural oscillations in the climate system, like the El Niño-Southern Oscillation and the Pacific Decadal Oscillation, that can modify the global-scale response at a particular location for years or even decades, making the response to increased greenhouse gas concentrations larger or smaller. Notably, the global-scale warming influence of human-made greenhouse gases will not only be superimposed on top of all these natural cycles, but may also influence their behavior. At the local to regional scale, additional influences—such as air pollution, land cover change, and urbanization—can also contribute to localized warming or cooling.

Indeed, because of the complicated dynamics of changes in the circulation of the atmosphere and the oceans—changes that can be caused by the effects of greenhouse gases or by human and natural forces that are independent of greenhouse-gas increases—it is perfectly possible, and indeed is often predictable, that some regions will become cooler on average even as the Earth as a whole grows warmer on average. And, of course, some regions will warm *faster* than the world as a whole is warming, as for example is happening in the Arctic for reasons that are quite well understood. Based on global-scale "fingerprint" studies that compare complex patterns of temperature and other aspects of climate from observations and climate models, we generally expect warming to be greater over land areas than over the oceans (due to differences in heat capacity), greater at mid to high latitudes than at low latitudes (due to more energy going into evaporation in lower latitudes), and greater in the winter than in the summer (again due to more heat going into evaporation during the summer). These tendencies are based on long-term projections and may or may not apply in all regions or localities, especially in the early stages of warming. Nevertheless, it is clear that over the next century, the human-caused amplification of the greenhouse effect will exert a dominant influence on average temperatures at sub-continental to global scales.

Question 3. Please explain the meaning of 'scientific consensus' and comment on the status of the science of climate change in the scientific and academic community.

Answer. The validity of scientific propositions is not determined by popular vote or even by a vote among scientists. It is determined by the replicability of observations, experiments, and analyses and the demonstrated predictive value of theories based on these, as certified by peer review. Peer review takes place when papers submitted for publication in scientific journals are reviewed by "referees" chosen by the editor, as well as when other scientists critique and try to replicate published results and when bodies such as the National Academy of Sciences and the IPCC use committees of scientists to review the state of understanding on specific issues.

At any given time, in any given scientific discipline, there is a set of understandings of the subject constituting what most competent specialists in the field consider to have been established. These understandings relate to what these specialists believe is known with high confidence, what they believe is probably true but not yet established with such high confidence, and what they believe the important questions are that need further investigation before conclusions can be drawn about them with any confidence at all. This set of understandings of a topic—the understandings held in common by most competent specialists in the relevant field—is what is meant by the term "scientific consensus".

The term does *not* mean some sort of average or common understanding held by everybody who is a scientist of any kind. Science is divided into many disciplines and specialties, and specialists in one topic are not necessarily much better informed about the science of topics outside their specialties than are laypeople. (Indeed, an intelligent layperson who has made a serious effort to learn about a particular scientific topic will probably know more about it than a scientist from a different specialty who has not made such an effort.) Thus, one would not try to determine the "scientific consensus" on climate change by polling a random sample of scientists of all specialties. One does it, as the U.S. National Academy of Sciences and the IPCC have done it, by convening a representative sample of the leading specialists to review and discuss current understandings and write down what they come up with in a report, which is then subjected to further review by additional leading specialists as to its accuracy and clarity.

Like all science, the science of climate change is evolving—a process in which old understandings are strengthened, modified, or discarded; earlier questions are wholly or partly answered (or found to resist answers); and new questions emerge. Disagreement and controversy are a normal part of this process. Much of the attention of scientists tends to be focused on questions that are not yet settled, and it is the healthy habit of some fraction of the scientific community to be constantly challenging understandings that most others have accepted. Scientific reputations are made not only by answering questions that no one was able to answer before, but also by showing that some understanding that was previously commonly accepted is in fact not adequate and requires modification.

The possibility of making their reputation by overturning accepted scientific wisdom motivates the "heretics" who are found in every scientific field. But policy makers and the public need to know that such reversals of accepted understandings are far rarer than popular accounts of science often suggest. In any given field at any given time, the odds are that most of the understandings held in common by most of the specialists in that field are right or close to right. The greater the body of accumulated evidence and analysis that supports those understandings, moreover, the lower is the chance of their being overturned. And even in the most celebrated scientific "revolutions", such as that produced by Einstein's theory of special relativity, the "old" understandings often remain adequate for most purposes. (Special relativity notwithstanding, the old Newtonian mechanics remain perfectly adequate for predicting what will happen when you drive your car at 60 mph into a brick wall.)

The "scientific consensus" on climate change—the understandings of climate science currently held in common by almost all scientists in this field—is based on a very large body of evidence and analysis from a wide range of relevant scientific disciplines and approaches, accumulated by thousands of researchers in universities, research centers, and field stations all around the world over a period of many decades. The robustness of the consensus view is based on:

- the sheer volume of evidence and analysis (which has expanded at a greatly increased rate over the past 15-20 years);
- the consistency of the picture that results from different types of observations and different modes of analysis (direct measurements of greenhouse-gas concentrations and the temperature of the ground and atmosphere and oceans; inferences about earlier concentrations and temperatures from glaciers, tree rings, sediments, and the like; application of fundamental principles of atmospheric physics; and computer simulations of past and future climatic change); and
- an intensity and rigor of peer review unusual even by the ordinary standards of science, resulting from the obvious importance to society of getting this particular science right and manifested in the extraordinary number and depth of multiply peer-reviewed reports on the science of climate change by the U.S. National Academy of Sciences, the IPCC, and a number of other national and international scientific bodies.

The scientific consensus view on climate change will continue to evolve as measurements and analyses continue. It is highly unlikely, however, that this evolution will change the current core understandings—namely that the Earth's climate has recently been changing in a manner that is unusual against the backdrop of normal variation from natural causes, that increased atmospheric greenhouse-gas concentrations from human activities are playing a large role in these changes, and that continuation along the current path will lead to additional climatic changes that are, on balance, increasingly harmful to industrialized and developing countries alike—in any fundamental way. The evolving understandings will, instead, provide more detailed and reliable information than currently available on the character, geographic distribution, and timing of future climatic changes and on the impacts of these changes. It is important for policy makers to recognize that this more detailed and reliable picture is at least as likely to be more alarming than the current scientific consensus, as described by the National Academy of Sciences and the IPCC, as it is to be less alarming than these current portrayals.

Question 4. What is "abrupt climate change?" Can you identify any potential thresholds that might be crossed if insufficient action is taken to control CO_2 emissions? For example, I have heard that beyond certain temperature increases, large ice sheets could collapse, leading to huge increases in sea level. Can you comment on this and other potential thresholds?

Answer. Improved methods for reconstructing the past climate of the Earth from "paleoclimatological" evidence such as the composition of gas bubbles trapped in the Greenland and Antarctic ice sheets have made plain that the climate has sometimes changed more abruptly in the past than had previously been supposed—for example, making a transition from an interglacial to a glacial period, or the reverse, in a matter of one to a few decades, rather than centuries. The fact that such rapid changes in outcome have been possible under gradually changing, natural "forcings" of Earth's climate is anything but reassuring in the context of the relatively rapid changes in "forcing" being generated by human-caused greenhouse gases today. If climate changes abruptly rather than gradually, the possibilities for adaptation by means of altered agricultural practices and patterns, construction of dams and dikes, and so on become much less promising.

To understand the possibility of abrupt or "non-linear" climate change it may be helpful to think about a light switch. If you first apply only a little bit of force to the switch, it doesn't move and no light comes on. But if you progressively add more pressure, you will eventually "flip the switch" and the light will come on. The light produced is not proportional to the pressure applied; that is, you don't get a little bit of light as you add a little bit more pressure. The light turns on once you push hard enough to move the switch. Similarly, the Earth's climate system is likely to contain thresholds that could conceivably initiate or accelerate abrupt climate change once the "forcing" caused by increased atmospheric concentrations of greenhouse gases reaches a certain level. One example of such a threshold might involve sudden shifts in the thermohaline pattern of ocean circulation. As warming temperatures melt the ice at the poles, salty ocean waters will be diluted with freshwater. Paleoclimatic records suggest that it is possible this gradual freshening of the sea, if it reached a certain level, could "flip a switch" and greatly diminish or even shut down deep ocean currents that are important in transporting heat and nutrients from the equator to the poles via global ocean circulation patterns. The result could be significant changes in regional weather patterns.

Crossing certain temperature thresholds could also trigger the initiation of rapid and irreversible melting of the Greenland Ice Sheet or a sudden destabilization of the West Antarctic Ice Sheet, either of which would raise global sea levels by about 20 feet. Another possibility is that temperatures could increase enough to trigger large-scale decomposition of methane clathrates (with attendant large amplification of the greenhouse effect). Unfortunately, knowledge of these possibilities is not yet sufficient to enable confident prediction of whether and when they would materialize along the warming trajectory now being traveled. Knowledge of these possibilities is, however, sufficient to conclude that we would be wise to slow the rate at which we are adding pressure to the switch—in this case, by pushing up atmospheric concentrations of heat trapping gases.

To underscore this point, another analogy may be helpful. We can think of ourselves as being on a CO_2 "highway" that is taking us to a rapidly warming future. By adopting more or less aggressive measures to curb emissions we can exit this highway at various places and thereby stabilize atmospheric concentrations of heat-trapping gases at various levels. At the moment, however, we are whizzing past exits, and with each one that goes by the risk grows that we may be passing a threshold. For example, as rising CO_2 concentrations both increase global temperatures and acidify the oceans, coral reefs may already be destined for large-scale devastation. We may have already passed that point of no return, but we can't be sure since we don't know exactly which exits mark different thresholds for drastically changing the way our planet operates.

The problem is that we are not likely to know that we have missed an exit or crossed such a threshold until it is too late to alter the outcome. Because CO_2 remains in the atmosphere for centuries, we can't wait and then make quick corrections once we see the results. Meanwhile, the faster we travel the more difficult it becomes to safely turn off the highway at any given exit. Thus, slowing our current emissions trajectory may be our best hope for anticipating and ultimately avoiding really abrupt and potentially catastrophic climate changes. By doing so, we can buy time to further develop our understanding of Earth's climate systems and to develop the new energy technologies that will be needed to stabilize future atmospheric greenhouse gas concentrations.

Question 5. Can you tell us something about the time horizon for stabilizing climate, given how long carbon dioxide remains in the atmosphere? Do we need to begin to control emissions now or can we wait?

Answer. Human additions of CO_2 to the atmosphere produce long-lasting increases in the total quantity of CO_2 in the atmosphere—which boosts the greenhouse effect because, while some portion of any additional carbon is quickly removed through uptake by plants and by the surface layer of the oceans, much of the carbon remains for decades and some of it remains for centuries. Every increase in the CO_2 content of the atmosphere, moreover, initiates changes in the climate that themselves grow for decades (due to the inertia of the climate system). The consequences of a given increase in temperature, moreover, may continue to build for centuries after the increase occurs. (This is the case for the rise in sea-level is likely to result from continued warming, for example.)

Thus, even though some effects are immediate, the *full* effects of any human additions of CO_2 and other greenhouse gases to the atmosphere will not be felt for decades and centuries after the additions occur. Prudence therefore requires controlling emissions long before the climate-change impacts being experienced have become intolerable. Given that harmful effects of greenhouse-gas-induced climate change are *already* being experienced at a global-average temperature increase of around 0.8 degrees C (1.4 degrees F) above the pre-industrial level, and given that the full effect of *current* greenhouse-gas concentrations will be a further increase of about 0.6 degrees C (1.1 degrees F) by the time the ocean reaches equilibrium with the increased greenhouse effect that these concentrations entail, we would be foolish not to start controlling the offending omissions immediately.

Question 6. Given that there is still some uncertainty about the details of future warming, how should such uncertainty be dealt with in designing policy responses?

Let me begin my answer by once again suggesting an analogy. If you go to your doctor and he says that if you continue on your present course, you are at very high risk of having a heart attack, what do you do? Do you ask exactly what day the heart attack will come and how severe it will be? Or do you take action right away to diminish your risk and try to prevent an attack?

Similarly, based on what we know now about the risks associated with rising greenhouse gas concentrations in the atmosphere, there is a clear need to begin reducing emissions right away if we are to improve our odds of avoiding the potentially severe and dangerous types of consequences that lie ahead. We know that the risk of "dangerous anthropogenic interference" in the Earth's climate is going to continue to grow until we address it. Economists have analyzed the costs of various policy responses and they tell us that there are more and less cost-effective ways to go about managing this risk. The most cost-effective emissions trajectories involve starting now to control emissions, just as it is best to initiate one's retirement savings early and benefit from the compounding of interest over time. Delay will be costly, and is likely to require an even greater allocation of resources in the long run. Doing less (or nothing) to control emissions now makes it more likely that we will have to do more later—and do it more abruptly. As the joint statement of the national academies pointed out, this is likely to be more expensive because it is difficult for economies to adjust to abrupt policy changes. It is thus not only more prudent, but more economically efficient to begin taking action now—preferably by implementing a policy that sends a clear signal to the market about the cost of emissions. A well-designed policy to accomplish this can also provide important ancillary benefits by promoting efficiency, reducing oil imports, improving air quality, and giving U.S. companies a competitive edge in the development and deployment of new energy technologies.

Question 7. How do we know that emissions of carbon dioxide and other greenhouse gases are causing Earth's temperature to rise, as opposed to other factors that we have no control over; such as sun spots? Some assert that an increase in solar irradiance is the main cause of the Earth's current warming trend. Therefore, reducing fossil fuel emissions would not impact the Earth's temperature.

Answer. The sun's radiant output is one of many factors that affect the Earth's climate. Scientists have intensively studied these various factors and how much they have influenced climate over the past century. "Fingerprint" studies analyze patterns of temperature change in models and in observations to help understand the causes of climate change. For example, were recent warming trends being caused by an increase in solar irradiance, one would expect the stratosphere to be warming also. This is not the case—in fact, the stratosphere is cooling. Similarly, if sunspots are the main cause of warming, then warming trends should correlate with sunspot activity. Again, this is not the case. Instead, global average surface temperatures have continued to rise with rising atmospheric concentrations of greenhouse gases. According to the IPCC, the warming effect due to increased greenhouse gas concentrations in the atmosphere over the past century is estimated to be more than eight times greater than the effect of changes in solar irradiance. In fact, observations do not even show an increase in average solar output over the past 50 years. Numerous peer-reviewed studies have concluded that natural factors, including solar output, could not have caused the observed warming of the past half century.

Question 8a. There are some who question the veracity of the assertion that the earth has warmed substantially over the last century. Arguments typically fall into three categories. It would be useful if you would address each in turn:

Urban Heat Island Effect. This is the claim that the underlying temperature data is tainted by the proximity of data-generating thermometers to cities. As urban areas have grown over the last fifty years, the air temperatures around these cities have increased due to larger amounts of heat generating substances like rooftops and roadways. Scientists claim to have corrected for the urban heat island effect. How was this done, and how can we be sure that it was done correctly?

Answer. The "urban heat island effect" is a spatially nonuniform warming effect from human activities that some climate-change skeptics have claimed has distorted the temperature record of the last 100 years so as to cause an overestimate of the effects of greenhouse gases. Some (including the author Michael Crichton in his recent novel) have claimed that much or all of the entire observed global warming is an artifact resulting from many of the measurement stations being in cities, which are warmer than the surrounding countryside because of the heat released in the operation of vehicles, factories, and homes. While a few disreputable skeptics continue to claim this, the fact is that their hypothesis has been completely discredited by much-replicated studies that carefully correct the analysis of temperatures from the global thermometer network for the effects of urban heat release.

To correct for the urban heat island effect, for example, scientists have compared temperature measurements taken in rural vs. urban areas and in some cases have simply excluded measurements taken at urban sites. Meanwhile, studies that compare global time series made up of temperature measurements taken only at rural stations with time series that also include temperature data from urban stations have found no difference between the two, suggesting that there is no bias in the global temperature trend due to urbanization[1] In another recent study using different methods, Parker (2004) also found no effect from urban warming in the global average temperature record.[2]

Finally, it is worth noting that thermometer readings are not the only evidence of warming. Glaciers on every continent, none of which are located in urban environments, are retreating. Rising sea levels, increasing ocean temperatures, thawing permafrost, and movement of animal and plant species all provide additional evidence of a global warming trend that cannot be explained by the urban heat island effect.

Question 8b. Satellite and Airborne Balloon Data Contradict Surface Temperature Readings. Global mean temperature at the earth's surface is estimated to have risen by about half a degree F over the last two decades. On the other hand, satellite measurements of radiances and airborne balloon observations indicate that the temperature of the lower to mid-troposphere (the atmospheric layer extending from the earth's surface up to about 8 km) has exhibited almost no change during this period. Please explain whether this discrepancy is, indeed, real and how to account for it.

Answer. Recent peer-reviewed studies have shown that the low-and mid-troposphere have in fact warmed at about the same rate as the Earth's surface over the past few decades. The earlier notion that the troposphere had not warmed was based on significant errors in the adjustment of satellite and balloon data. As these errors have been corrected, the temperature data for the low-and mid-troposphere have consistently shown more warming.[3] Studies to be published this month (11 Au-

[1] See, for example, Peterson, T.C., K.P. Gallo, J. Lawrimore, T.W. Owen, A. Huang, and D.A. McKittrick, 1999: Global rural temperature trends. *Geophys. Res. Letts.*, 26, 329-332 and Peterson, Thomas C., 2003: Assessment of urban versus rural in situ surface temperatures in the contiguous U.S.: No difference found. *J. Climate*, 18, 2941-2959.

[2] Parker, D.E., 2004: Large-scale warming is not urban, *Nature*, 432, 290-291, 10.1038/432290b.

[3] See, for example, Mears, C.A., M.C. Schabel, and F.J. Wentz, 2003: A Reanalysis of the MSU channel 2 tropospheric temperature record. *J. Climate*, 16, 3650-3664; Vinnikov, K.Y., and N.C. Grody, 2003: Global warming trend of mean tropospheric temperature observed by satellites. *Science*, 302, 269-272; Vinnikov, K.Y., A. Robock, N.C. Grody, and A. Basist, 2004: Analysis of diurnal and seasonal cycles and trends in climatic records with arbitrary observation times. *Geophys. Res. Lett.*, 31, L06205, doi:10.1029/2003GL019196, 2004; Lanzante, J.R., S.A. Klein, and D.J. Seidel, 2003: Temporal homogenization of monthly radiosonde temperature data. Part

Continued

gust 2005) in Science expose the latest of these errors (see Sherwood et al., 2005 for balloon data; and Mears and Wentz, 2005 for satellite data).[4] In addition, the rate of warming both at the surface and in the troposphere has increased in the years since initial analyses of satellite and radiosonde data were undertaken.

Though there are still minor discrepancies between available data sets due to the different methods that different research teams use to analyze the data, the bottom line is that both the surface and the troposphere show significant global warming trends according to all available data records: those derived from thermometers at the surface, those derived from sensors on satellites, and those obtained from weather balloons. These records show no major difference between surface and tropospheric warming at the global scale over the past several decades.

Question 8c. The Hockey Stick. In recent months, there have been assertions that the statistical method used to analyze global temperature data for the last several hundred years was biased towards generating the "hockey stick" shaped curve that shows sustained low and stable temperatures for hundreds of years with an extremely sharp rise in the last 100 years. Can you comment on whether the observations depicted in the hockey stick curve are, indeed, legitimate?

Answer. The "hockey stick" shape of reconstructions of Earth's temperature over the past 1,000 years, which shows a sharp rise in temperature over the last 100 years, is a feature that is found in, or supported by, many different lines of measurement and analysis by many different investigators. It appears, for example, in studies of the extent of glaciation in mountain regions, gas bubbles trapped in the Greenland and Antarctic ice sheets, tree rings, pollens preserved in sediments, and borehole measurements of temperatures at various depths in Earth's crust. The critiques that have been offered of the statistical techniques that were used to produce one particular version of the "hockey stick" graph—a version that was prominently displayed in the 2001 climate-science report of the IPCC—would not invalidate this general conclusion even if the critiques were correct. But it now seems quite clear, both from the responses offered by the authors of that graph and from analyses that are becoming available from others, that these critiques are wrong.

In addition, it should be stressed that the details of the shape of the 1000-year "hockey stick" are not an essential element of the key understandings in the current scientific consensus about climate change—namely, that the planet is now warming at an unusual rate and that this current warming is primarily due to human activities. A very large number of independent studies have led to this conclusion.[5]

Question 9. Some say that global warming might be a positive development? Will agricultural crop productivity improve due to the greater amount of CO_2 in the atmosphere, and can we expect the Arctic and Antarctic regions to become more habitable?

Answer. The effects of climate change on agricultural productivity depend on numerous inter-related factors, including rising temperatures, increased CO_2 in the atmosphere, average precipitation levels, incidence and severity of floods and droughts, and the plant-pest-and-pathogen-promoting effects of a warmer, wetter world. Early studies that ignore the pest-and-pathogen and flood-drought issues have suggested that a modest increase in global-average temperatures would increase agricultural productivity in some areas, while reducing it in others. Even these limited predicted benefits are confined to small increases in temperature, however, with overwhelmingly negative effects setting in when temperatures reach levels expected in many agricultural regions by the middle of this century. More recent studies that account for a fuller range of climate-linked effects on crops suggest that net negative impacts on world agriculture are likely even sooner.

Modest amounts of global-average warming will have both positive and negative impacts on other aspects of human health and well-being as well. In some mid-latitude regions, for example, slightly warmer winter conditions might have some positive consequences (e.g., lower heating bills) as well as some negative ones (e.g., diminished mountain snowpack could further strain already inadequate water supplies in western parts of the United States). But in these non-agricultural respects, too, the net impacts are likely to turn strongly negative for most nations, people, and biological systems above a certain threshold—both because the rate of climatic

I: Methodology. *J. Climate*, 16, 224-240 and Lanzante, J.R., S.A. Klein, and D.J. Seidel, 2003: Temporal homogenization of monthly radiosonde temperature data. Part II: Trends, sensitivities, and MSU comparison. *J. Climate*, 16, 241-262.

[4] Sherwood, S.C., J.R. Lanzante, C. Meyer, *Science*, 11 August 2005: Radiosonde daytime biases and late 20th Century warming. (10.1126/science. 1115640) and Mears, C.A., and F.J. Wentz, *Science*, 11 Aug. 2005: The effect of diurnal correction on satellite-derived lower tropospheric temperature.

[5] A thorough analysis of the hockey stick debate can be found at *www.realclimate.org*.

change is likely to require continual adjustment and because negative impacts will begin to overtake positive ones.

The recent Arctic Climate Impact Assessment presented evidence that strong negative impacts are already affecting the Arctic and that these negative impacts are likely to intensify as warming proceeds. Impacts that are already being registered include severe coastal erosion due to retreating sea ice, rising sea level, and thawing of coastal permafrost and attendant damage to buildings, roads, and industry. More severe insect outbreaks and more frequent forest fires are also likely to accompany ongoing warming. The warmest regions of the world, meanwhile, may begin to experience conditions that are virtually unprecedented for human societies and natural ecosystems. In sum, the evidence is strong that negative impacts are very likely to outweigh positive ones as rapid warming proceeds.

Question 10. It is my understanding that the assessments of the progression of global warming through the next century and its impacts on changing the Earth's climate are largely based on computer modeling. It goes without saying that the planet's atmospheric, hydrologic, and meteorological systems are highly complicated. What can you say about how climate modeling capabilities have advanced since scientists began evaluating the problem? What is the level confidence that the computer models are providing useful projections of the future climate?

Answer. You are correct that we gain most of our insight into what the future holds by utilizing complex, physically-based computer models. These models are quantitative and grounded in the fundamental laws of physics and chemistry and are anchored by a very large number of scientific measurements. Our confidence in the models is strengthened by the fact that they can replicate past and present climates as well as the influences of the most important factors that affect climate. The models are extensively compared, tested, and refined, and they provide us with valuable insights. Climate scientists do not use the models blindly, they analyze and understand them and check them against everything else that they have learned.

That said, models are not the only tools scientists use to predict what will happen as greenhouse gas concentrations continue to rise. Records of past climatic conditions derived from ice cores, tree rings, and other data, and observations from the past century also provide evidence regarding how climate changes and what the impacts of such changes are likely to be. There is no past analog to the geophysical experiment that our species is now undertaking—and is committed to for some time into the future. Although models may provide only an indication of what is most likely to occur, they are among the most important tools we have for anticipating the consequences of a changing atmosphere rather than simply facing those consequences without warning.

Question 11. You played a central role as a scientist in the debate surrounding the stratospheric ozone hole, which led to a resolution that is widely regarded as one of the most important and successful international environmental agreements ever. Do you see any key similarities between the two issues (stratospheric ozone layer and climate change) and, more importantly, can you comment on any key lessons that might be applicable to the current debate on whether and how to address climate change?

Answer. Ozone is a highly reactive, unstable molecule consisting of three atoms of oxygen. It occurs both near the Earth's surface—where it is a major constituent of smog, and in the region of the upper atmosphere, six to thirty miles above the surface. Paradoxically, while surface ozone is harmful to human health and the environment, the "other" ozone—that in the stratosphere—is absolutely necessary for life.

Research has been key to understanding how stratospheric ozone blankets the Earth and helps make it a livable planet. Stratospheric ozone forms an invisible shield protecting us from the hazardous ultraviolet radiation that streams towards the Earth continuously from the sun. UV-B radiation can directly harm people. For every 1% increase in UV-B radiation, there will be about a 2% increase in non-melanoma skin cancer in light-skinned people. We currently have about 750,000 new cases of skin cancer each year in the United States, of which between 0.5% and 1% will result in death. Increased exposure to UV-B radiation can also cause cataracts, which are already the third leading cause of blindness in the United States. Increased UV-B radiation is also associated with decreased immune system response in all populations.

The story of how we reached these international agreements began twenty years ago when Sherwood Rowland and I hypothesized that chlorofluorocarbon molecules (CFCs) are stable enough to diffuse to the stratosphere where the sun's ultraviolet radiation would split off the chlorine atom, whereupon each chlorine atom would act as a catalyst, destroying thousands of molecules of ozone.

Back then there was little but laboratory data and numerical models to support the hypothesis. In fact, all we really knew was that CFC concentrations in the atmosphere had been rising and that a seemingly plausible, but unproven, hypothesis existed that chlorine from CFCs could destroy ozone.

CFCs were invented in the early 1930s as a replacement for hazardous compounds like ammonia that were then widely used as refrigerants. CFCs are odorless, extremely stable, relatively non-toxic, and nonflammable. Not surprisingly their use quickly spread to a wide range of industrial and consumer applications, from refrigeration to aerosols propellants to foam products and eventually as solvents in the electronics industry.

Given the scientific consensus that now exists, it is hard to imagine the controversy that surrounded this theory two or three short decades ago. In part, this controversy was driven by the lack of clear and convincing evidence in support of the hypothesis, but it was also driven by a concern that CFCs were critical to our quality of life and no substitutes existed to replace them.

How then did we quickly evolve from a politically charged situation in the late 1970s to today where 150 nations of the world have agreed to phase-out CFCs by the end of this year in all developed countries and soon thereafter in developing countries?

First and foremost, this issue has been driven by major and definitive advances in our scientific understanding. We have gone well beyond our rudimentary knowledge in 1974 of the impact of CFCs on ozone chemistry. While uncertainties remain, laboratory and field experiments, observations, and more extensive model simulations have enabled us to become much more confident about the atmospheric processes that control stratospheric ozone and the role that CFCs and other chlorinated and brominated compounds have on those processes.

The most striking example of our new understanding concerns the so-called Antarctic ozone hole. When ground-based and satellite data were first published showing the existence of this ozone hole, which opens in the Antarctic spring, the scientific community, not to mention the public at large, were taken completely by surprise. No models or theories had predicted any such phenomenon. At first, the scientific community was at a loss as to explain its cause. Was it due to CFCs, the result of some meteorological conditions, or was some other unknown factor at work? Was the condition unique to Antarctica, to polar conditions in general, or likely to affect global ozone levels?

These were more than interesting questions for the scientific community to debate. Just about the same time news about the ozone hole surfaced in the scientific literature, nations were coming together to discuss what actions they should take to protect the ozone layer. But a definitive policy decision was dependent on a sound scientific understanding of the issue.

In what must be considered record time and with broad international and public and private sector cooperation, two major scientific campaigns were organized in 1987 and again in 1988 to collect data concerning the Antarctic ozone hole. Based on extensive field measurements, lab experiments and modeling, the consensus view emerged that CFCs cause the depletion of ozone over Antarctica.

This finding brought a sense of urgency to policy makers. As we all know, ozone is a global issue and requires a global response. Reductions in the use of CFCs in the United States—even though the United States was the major source of CFCs—were not going to solve the problem if other nations continued to expand their own use. Subsequently, a series of international scientific studies were conducted. These reviews began in the 1970s and were formally brought into the Montreal Protocol when it was signed in 1987. They have become the bedrock foundation upon which policy decisions concerning ozone depletion are taken.

The original Montreal Protocol called for a 50% reduction in CFCs by 1998, but also called for periodic review of scientific and technology issues. The first such review was issued in 1989 and led the Parties to agree, first, that—on the basis of new scientific information—even greater reductions were needed to protect the ozone layer and second, that chemical substitutes had advanced enough to make practical the full phase-out of CFCs by the end of the century. It is important to emphasize that extraordinary technological progress by the industrial sector in developing CFC alternatives permitted a faster phase-down. A similar process in 1992 led to agreement that CFCs would be phased out in the developed world by the end of this year.

Let me summarize the evidence that is now very clear and broadly accepted by experts around the planet:

1. There is no doubt that the major source of stratospheric chlorine and bromine is from human activities (e.g., CFCs and halons), not from natural sources such as volcanoes or sea spray.

2. There is no doubt that downward trends of stratospheric ozone occurred at all latitudes, except the tropics, during all seasons. The overwhelming weight of scientific evidence suggests that the observed mid-latitude downward trends of ozone were due primarily to anthropogenic chlorine and bromine.

3. There is no doubt based on combining ground, aircraft, balloon and satellite data, with laboratory data and theoretical modeling—that the spring-time Antarctic ozone hole is due to anthropogenic chlorine and bromine.

4. During periods of declining ozone, stations in Antarctica, Australia and mountainous regions in Europe, have shown that ground-level UV-B radiation increases, as is expected to occur with reduced ozone concentrations.

5. The rate of increase of atmospheric chlorine and bromine in the atmosphere has slowed considerably in the last few years, demonstrating the effectiveness of actions taken under the Montreal Protocol and its amendments. Even so, and if everything goes forward smoothly, the mid-latitude ozone loss and the hole over Antarctica are not expected to disappear until the middle of the 21st century.

LESSONS LEARNED FROM THE MONTREAL PROTOCOL

The story I have told about the ozone layer shows science, technology, and policy moving forward in harmony. Four factors are important in understanding the sources of the Montreal Protocol:

1. Evolving scientific understanding of the problem did not hamper development and implementation of mandatory policies,

2. Once mandatory policies were in place, the rate of technological progress exceeded our most optimistic expectations,

3. The United States and other industrialized nations were willing to take a leadership role and move ahead of developing nations, and

4. The availability of acceptable substitutes for CFCs was an important ingredient in garnering widespread political support, particularly from the business community.

In my opinion, these same factors are necessary for progress to address global climate change effectively.

RESPONSES OF DR. MARIO MOLINA TO QUESTIONS FROM SENATOR BUNNING

Question 1. Would you say that the steps America has taken in the recent years to improve energy efficiency and produce lower carbon emissions from power generation are the right first steps in addressing climate change? Within that construct, given the current U.S. electricity supply that is more than 50% derived from coal, is encouraging clean coal technology, IGCC and carbon sequestration the most important immediate policy action we can take?

Answer. Coal is obviously an extremely important part of our current energy mix and plays an especially significant role in the generation of electricity. It is also a relatively low-cost fuel and one that the United States possesses in abundance. For these reasons, all NCEP members agreed that it was critical to advance technologies—like IGCC with carbon sequestration—that will allow coal to continue to play an important role in meeting the nation's and the world's energy needs over the long run. As we put it in our report: "cost-effective technologies that would allow for continued utilization of coal with substantially lower greenhouse gas emissions could represent a significant breakthrough—one that would make policy responses to the risk of climate change compatible with a new era of expansion for the coal industry." Because such technologies would advance a variety of economic, environmental, and energy security objectives, NCEP strongly agrees that developing clean coal IGCC technology and carbon sequestration is an important near-term policy priority. Accordingly, our report recommends substantially increased federal funding for research, development, demonstration and early deployment initiatives in this area. The funding levels we recommended are explicitly designed to support the early deployment of roughly 10 gigawatts (GW) of commercial-scale IGCC power plant capacity, together with additional projects to demonstrate carbon sequestration at a variety of sites around the country.

While NCEP agrees that promoting coal IGCC with carbon sequestration is a critical policy priority, we also believe it cannot be our only policy priority if we are serious about addressing climate change. There are at least two reasons why technology incentives, by themselves, do not constitute an adequate response to the threat of climate change. First, in order for new technologies to succeed it is always more effective, and indeed often necessary, to pair a policy "push"—in this case public support for RD&D—with a "pull" from the marketplace. To create a market pull for coal IGCC and other climate-friendly technologies, markets need to put a value on avoided carbon emissions, so that utilities have clear incentives to pursue non- and low carbon alternatives and so that investors can justify putting money into new and less proven technologies.

The second point is that no one technology, by itself, can "solve" the climate problem. On the contrary, most experts believe that we will need a portfolio of solutions that includes not only coal IGCC with sequestration but a variety of other options such as increased energy end-use efficiency, new nuclear technology, more natural gas technologies, and renewable energy options like wind and solar power. The importance of promoting a broad array of solutions rather than putting all our eggs in one technology "basket" again points to the need for a comprehensive policy framework that can create consistent incentives throughout the economy for avoiding carbon emissions. A mandatory, market based emissions trading program such as we have proposed for limiting carbon emissions is necessary to create those consistent incentives and is the critical complement to all other policies aimed at advancing a particular technology solution, be it coal IGCC or another low-carbon alternative.

To sum up, all the efforts that have already been made to improve efficiency in the electric sector and to reduce carbon emissions from electricity generation are important and have helped to keep atmospheric concentrations of carbon dioxide lower than they otherwise would be. For all the reasons I have described above, however, these early efforts must now be followed by the crucial next step of implementing an overarching, mandatory policy for gradually limiting greenhouse gas emissions in the future. My NCEP colleagues and I believe that, over time, such a policy will not only prove most effective at promoting new technologies like coal IGCC with carbon sequestration, but will also prove the least costly approach for addressing the risks posed by future climate change.

Question 2. As a member of the NCEP, you described the NCEP findings as a scientific analysis of why "business as usual" can not continue. Given the major government initiatives, most notably the Energy Bill we wrote in this committee, wouldn't you agree that America is no longer operating "business as usual"?

Answer. The recently passed energy bill contains a number of provisions that I and other members of the NCEP strongly support, including new incentives for a variety of technologies that will help make our nation more energy secure while also reducing our greenhouse gas emissions. By themselves, however, these measures are unlikely either to significantly alter our future greenhouse gas emissions trajectory or to maximize the results achieved through additional government expenditures on new technologies. In a competitive market-economy, where companies are encouraged and in some cases obligated to maximize shareholder value, it is contrary to the rules of free-market competition to expect companies to invest scarce resources absent a profit motive. While there are numerous cases where a combination of good will, good public relations, and positive ulterior motives (like reduced energy bills), create an adequate basis for taking action, these cases will remain limited if the financial value of reducing a ton of greenhouse gas emissions remains zero.

Unfortunately, the energy bill—notwithstanding the progress it makes in other important areas—does not provide that clear market signal. It does not directly address climate, nor does it seek to limit future greenhouse gas emissions. So in that sense, I would argue we are still operating in a "business as usual" framework with regard to climate change.

Question 3. While you have presented what appears to be a united scientific front in the form of the statement from the academies of science from 11 countries, I am concerned by some of the news since the release of that statement. The Russian Academy of Sciences says it was misrepresented and that Russian scientists actually believe that the Kyoto Protocol was scientifically ungrounded. I am also aware that there was a significant misrepresentation on the science between our academy and the British representative. Given this background, wouldn't you say there are still some pretty fundamental disagreements about the science of climate change among scientists around the world?

Answer. I am not aware of the specific controversy or controversies to which this question refers and would defer to my fellow witnesses, notably Ralph Cicerone, for their view of the matter if in fact any such disagreements exist. I will, however, say that while I was not involved in drafting the national academies' joint statement on global warming, I fully endorse it and believe that it accurately reflects the considered, consensus view of the great majority of climate scientists around the world.

While scientists will always continue to debate details (because that is the primary way in which science advances), it is clear to me that mainstream scientists around the world are in fundamental agreement about the science of climate change.

Question 4. In this international academies statement, you find that an "immediate response that will, at a reasonable cost, prevent dangerous anthropogenic interference with the climate system," but continue to say in the following paragraph, "minimizing the amount of this carbon dioxide reaching the atmosphere presents a huge challenge." Could you please elaborate, since any response can't both be a "reasonable cost" and a "huge challenge" proposition, how you resolve the two?

Answer. As I noted in my previous response, I wasn't personally involved in drafting the academies' statement. Nevertheless, I believe its thrust is quite clear and that it is not, in fact, difficult to reconcile the two specific sentences juxtaposed in this question. Simply put, it is often the case that the best and most practical solution to a very big problem lies in approaching it with relatively small steps. It may be helpful to return to the analogy of the heart patient I introduced in response to Senator Bingaman's Question #6. If the patient does nothing now, but later requires emergency surgery or even an artificial heart, managing his condition will be expensive and risky and may require major advances in medical science. But the same patient can take early steps to reduce his risk of heart attack—such as changing his diet and exercising more—that are relatively easy and low cost. Of course, he may eventually still require more drastic treatment. But, at a minimum he can buy some time and significantly increase his odds of a healthy outcome over the long run.

I believe the national academies were trying to make a very similar point. Fundamentally altering our energy systems so that global greenhouse gas emissions not only stop owing but begin to decline in absolute terms clearly presents a huge challenge. But taking early steps to set in motion some of the long-term changes that will eventually be required can be done at reasonable cost. As in the analogy of the heart patient, timing is everything. The longer we wait, the more difficult it becomes to achieve any given stabilization target without incurring large, wrenching, and probably quite expensive changes to our existing energy systems. That's why the academies' statement urges governments to "recognize that delayed action will increase the risk of adverse environmental effects and will likely incur a greater cost."

The National Commission on Energy Policy shares this view. We too concluded that a lack of full scientific certainty must not be an excuse for inaction and that the key thing is to start now by taking cost-effective steps that will contribute to substantial long-term emissions reductions. That's why we recommended a very gradual program for limiting greenhouse gas emissions that explicitly holds costs to a reasonable level. Our proposal does not solve the climate problem—in fact, as our critics often point out, it allows U.S. emissions to continue to rise in the first decade of program implementation. But it does begin to generate the clear and quantifiable market signals that will be needed to elicit technological innovation and long-term investment in lower-carbon alternatives. That's a small step to be sure, but it may be our best hope for getting started and, by doing so, for turning climate change from an overwhelming challenge into a difficult, but manageable one.

Question 5. Several scientists have cited events like the high temperatures in Europe in the summer of 2003 and increased storminess in the 1980s and 1990s as evidence of climate change. Don't global ecosystems go through natural periods similar to these as well?

Answer. While it is true that there are natural climate cycles that can cause events such as those cited in this question, it is also true—based on a number of studies—that such events are likely to occur with far greater frequency as a result of human-caused increases in atmospheric concentrations of greenhouse gases. For example, a study by researchers at the U.K. Meteorological Office and Oxford University that used both field measurements and computer models concluded that the chance of a heat wave as severe as that of 2003 in Europe had at least doubled and probably quadrupled due to higher levels of greenhouse gases in the atmosphere.[6] The study further found that summers like 2003 (which would be an extremely rare event under normal circumstances) are likely to occur every other year by the middle of this century due to global warming.

As for severe storms, a recent study by MIT hurricane expert Kerry Emanuel (2005) shows that the destructive power of hurricanes has increased markedly over the past 30 years and that this increase is highly correlated with rising sea surface

[6] Stott, Peter, D.A. Stone, M.R. Allen, *Nature*, 2 December 2004, Vol. 432, Human contribution to the heatwave of 2003.

temperatures due to global warming.[7] This increase in destructiveness is due to both longer storm lifetimes and greater storm intensities. Other studies over recent years have shown that the incidence of heavy and very heavy precipitation events (i.e., major downpours) has likewise increased in recent decades, leading to increased flooding and erosion.[8] These trends have been similarly linked to the warming effects caused by human-induced increases in the atmospheric concentration of greenhouse gases.

Question 6. There are a number of astrophysicists and other scientists who believe that sunspots are a major contributor to changing temperatures. A recent survey showed at least 100 such studies are underway. Why don't scientists put as much emphasis on this possibility or other aspects of natural climate variability as they do on emissions from human activity?

Answer. Sunspots are a cyclical phenomenon—they increase and decrease with a period of about 11 years. Such short-cycle ups and downs do not produce long-term trends in climate. There is evidence that the output of the sun varies also on longer time scales, and there is much scientific interest in how this works and how it may have affected Earth's climate over geologic time. The IPCC's estimate in its 2001 report was that the role of changes in the sun's output in the climate forcing of the past 250 years is in the range of 10 times smaller than the role of anthropogenic greenhouse gases. And a wide variety of studies show that the rapid increase in temperature experienced in the last part of the 20th century and continuing today was not due to changes in solar output, which have been very small in this period.

"Fingerprint" studies based on complex patterns of temperature changes over the Earth and in different layers of the atmosphere have used observations and models to attribute the observed temperature record of past decades to particular factors that influence climate. Such studies have been helpful in determining which factors are most responsible for the observed changes. None of these studies have concluded that solar influences are a major factor in the observed trends. There is thus no scientific evidence to support the notion that sunspots or other natural variables are as important as human-caused emissions in explaining recent warming trends.

Question 7. Much of the discussion about climate science being settled is based on the summary chapter of the Intergovernmental Panel on Climate Change of the United Nations. The chapter made specific predictions about the pace of rising temperatures and the relative importance of human activities to climate change. And yet, the body of the report is much more ambiguous and inconclusive about the current state of the science. Is anything being done to ensure that the summary of the next IPCC report is more reflective of the overall analysis by the scientists?

Answer. It is simply not the case that the summary chapter is inconsistent with the body of the IPCC report. Rather, any differences in tone most likely reflect the difference between a document oriented to policy-makers and decision-makers vs. a document oriented to a scientific audience. The IPCC technical chapter authors conduct their analyses and communicate their results based on the traditional decision-making paradigm of the scientific community, namely to have 95% or better confidence that what you say is the correct explanation AND 95% or better confidence that there is no other alternative explanation. While this level of certainty is appropriate in the context of pure scientific inquiry it is rarely, if ever, achievable in the realm of policy making.

The IPCC Summary for Policymakers thus represents a translation of the significance of the scientific findings into terms that policymakers can work with. In making this translation, IPCC authors agreed on a specific lexicon (i.e., the sequence of words 'virtually certain,' 'very likely,' 'likely,' etc.) to define relative levels of likelihood and certainty based on best evidence and considered scientific judgment. The meaning of these terms is carefully spelled out in the IPCC report and their use is footnoted throughout the text. Of course, some scientists are not entirely comfortable with the results of this translation—after all, it is always possible for a reader to misunderstand the scientific nuances and to draw incorrect conclusions from necessarily qualitative terms such as "very likely" or "virtually certain". In the case of climate change, as with most other important public policy challenges, however, policy makers simply do not have the luxury of waiting until all scientific uncertainties are resolved before some difficult decisions must be made. As a result it will continue to be necessary to undertake the process of translation exemplified by the IPCC report's Summary chapter.

[7] Emanuel, Kerry, 2005, *Nature*, 4 August 2005, Vol. 436/4, Increasing destructiveness of tropical cyclones over the past 30 years.

[8] See, for example, Groisman, Pavel, R.W. Knight, T.R. Karl, Feb. 2001, Bulletin of the American Meteorological Society, Heavy precipitation and high streamflow in the contiguous United States: trends in the 20th century.

In sum, while I'm sure the IPCC will continue to work to improve its approach to communicating scientific understanding, this does not mean that the current Summary does not represent a fair and reasonable characterization of the best available climate science as the IPCC authors felt it should properly be applied in a policymaking context.

Question 8. The natural "greenhouse effect" has been known for nearly two hundred years and is essential to the provision of our current climate. There is significant research in the literature today that indicates humans, since the beginning of their existence, have caused an increase in the greenhouse effect. Some argue that the development of agriculture 6,000 to 8,000 years ago has helped to forestall the next ice age. The development of cities, thinning of forests, population growth, and most recently the burning of fossil fuels, have all had an impact on climate change. Our ecosystems have constantly adapted to change, as we as humans have adapted to our ecosystems as well. Is it possible that the increased presence of CO_2 caused by the 8,000 years of modern human existence may be something our ecosystems will continue, as they previously have, to naturally adapt to?

Answer. The advent of agriculture 6,000 to 8,000 years ago may have caused changes in the atmosphere which in turn triggered climatic changes, but those changes occurred within a range that had been experienced on Earth in the preceding million years. In other words, ecosystems had to readjust to conditions that had obtained at some point in the—geologically speaking—relatively recent past, rather than to an entirely new set of conditions. What is happening now is that the climate is responding to atmospheric conditions that have not occurred for at least several million years. Moreover, this change may be happening with unprecedented rapidity. Within a century, atmospheric CO_2 is projected to be at levels that have not been experienced on Earth in tens of millions of years. For natural ecosystems, then, the really key issue may not be how much the climate is changing, but how fast that change is occurring.

Climatic conditions have, until recently, also been relatively stable over the history of human civilization. Our present societies are adapted in many ways to conditions that have obtained for at least several centuries. Because of our technological prowess, human societies are likely to be better able to adapt to a rapidly changing climate than natural ecosystems, which can respond only slowly to changing conditions. But the pace of change will have important consequences for human adaptability as well. The more quickly buildings, infrastructure, agricultural practices, water systems, and other aspects of society are forced to change, the more costly it will be to adapt and the higher the toll is likely to be in terms of human morbidity, mortality, and diminished quality of life. This is especially true, of course, for impoverished nations that are already more vulnerable to changing natural conditions and that lack the resources of more developed societies to adapt effectively.

Finally, it is worth noting that if human activities 6,000 to 8,000 years ago could cause climatic impacts of the magnitude indicated by the above question, this implies that the far more significant changes we are now causing in the atmosphere are likely to have commensurately more dramatic consequences for global climate conditions.

Question 9. NCEP has previously explained that there are significant uncertainties, both scientific and technological, and that the best approach is "the search for a mix of affordable technical and policy measures." Given your support of this proposal, could you outline how and what measures you would enact?

Answer. This question may be primarily intended for other panelists who were not, as I was, active participants in the National Commission on Energy Policy (NCEP). Nevertheless I will say that, in a nutshell, the NCEP's recommended approach is to combine an initially modest, economy-wide, market based program for limiting future greenhouse gas emissions with substantial new public investments in developing and deploying advanced low-or non-carbon energy alternatives. Our specific recommendations are outlined in detail in the report we released last December. A summary of our proposal with respect to a tradable-permits program for limiting greenhouse gas emissions was provided in written testimony provided to the Committee by NCEP Executive Director Jason Grumet. The full report, copies of which have previously been given to the Committee and which is readily available from NCEP, also included two illustrative tables summarizing the scope of technology investments proposed by the Commission and their possible allocation, both as between (1) basic RD&D vs. early deployment incentives and international cooperation and (2) as between different technology areas (e.g., energy efficiency, advanced fossil fuel technologies, nuclear, renewables, etc.).

Question 10. The panel touched on some energy alternatives such as biomass, natural gas, and nuclear power, yet there was little mention of hydrogen power. From a scientific viewpoint, where do you think we are on being able to really utilize hydrogen power? What is the potential of hydrogen power?

Answer. The most important point to understand about hydrogen is that it is not an energy source like coal or nuclear energy or sunlight, but only an energy carrier (like electricity), which society can choose to produce from one or more of the available energy sources in order to improve the convenience, versatility, efficiency, or environmental characteristics of our energy system. Like electricity, hydrogen is very clean at the point of end-use (but not necessarily at the point of its manufacture), and also like electricity, hydrogen uses more raw energy in its production than the product contains. Society will choose to pay this energy price for hydrogen production when the "system" benefits in terms of the combination of cleanliness, convenience, and economics warrant it, but until now this has only been the case for chemical uses of hydrogen (such as in fertilizer production), not in the energy system.

One powerful motivation for pursuing the use of hydrogen in the energy system is that stripping hydrogen from hydrocarbon fuels such as coal, oil, and natural gas would provide a way to ha mess much of the energy content of these fuels while capturing the carbon for sequestration away from the atmosphere. This is, in essence, what happens in an Integrated Gasification Combined Cycle power plant with carbon capture, and what would happen in still more advanced coal power plants that used fuel cells for converting the hydrogen to electricity rather than burning the hydrogen in a gas turbine. Avoidance of the carbon emissions from autos, trucks, and buses would likewise be one of the main motivations for converting such vehicles to use hydrogen as fuel, along with the motivation that the hydrogen could be produced from a wide range of energy sources, not just from the petroleum that is the only important source of gasoline and diesel fuel for these vehicles today.

In developing our recommendations, other NCEP members and I gave considerable emphasis to the development of the coal-gasification and carbon-capture-and-sequestration technologies that are likely to be the earliest opportunity to benefit from hydrogen in the energy sector. We also examined the prospects for the use of hydrogen as a low carbon alternative to oil-based transportation fuels. We recognized that hydrogen in this role offered some theoretically impressive environmental and national security benefits and might have the potential, at some point in the future, to play an important role in the transportation fuel mix. We also, however, quickly reached the conclusion that a number of very significant technological challenges must be overcome to realize this potential. In fact, because these near-term technological hurdles are so significant we concluded that hydrogen in the transport sector offers little to no potential to improve oil security and reduce climate change risks in the next twenty years. Accordingly, while we remained supportive of basic research into hydrogen in portable applications as a potential long-term (i.e., roughly mid-century) solution, we also urged that efforts to speed the deployment of a hydrogen transportation system not displace other activities that could deliver far more significant results in terms of reducing greenhouse gas emissions and petroleum consumption over the next twenty years. I will note that the National Academy of Sciences, in a separate and more comprehensive report on hydrogen that was released in 2004, came to very similar conclusions.

Question 11. The panel established very clearly that we should adopt policies that decrease carbon emissions regardless of any other carbon emissions policies we pursue. We are currently or will shortly be providing expanded incentives for clean coal, nuclear energy and renewable fuels. Do you feel this is money well spent? What technologies do you feel the government should be more involved in developing?

Answer. As noted in my response to a previous question, the recently passed Energy Bill includes a number of provisions, including several important provisions related to technology incentives, that I and other members of NCEP support. As I have also previously stated, however, the effectiveness of these incentives is likely to be substantially undermined by the fact that they are not accompanied by a mandatory program that would place a firm financial value on avoided greenhouse gas emissions.

It is somewhat ironic that a number of European nations are implementing market-based regulatory approaches developed here in the Unites States while we pursue a top-down program of government-directed, tax payer funded research and deployment incentives. Developing and commercializing new technologies will cost money. The question is who is best positioned to secure and effectively spend these resources. While there is certainly a role for public funding and government incentives, the Commission believes that there must also be a role for those who emit greenhouse gases to share in the costs of developing solutions. As we have learned over the last twenty years, given a rational reason to invest, the private sector is far better than the government in developing technological solutions. The success of the acid rain program demonstrates that the most effective way to engage the ingenuity of the private sector is to place a monetary value on a ton of reduced emissions thus creating a real economic incentive to develop cleaner forms of energy.

RESPONSES OF DR. MARIO MOLINA TO QUESTIONS FROM SENATOR TALENT

Question 1. In your testimony, you state that "the climate system is very complicated and science does not have all of the answers." Also, "There is of course much we do not fully understand about the timing, geographic distribution, and severity of the changes in climate . . . that will result if heat-forcing emissions continue." Finally, you add that "not knowing with certainty how the climate system will respond should not be an excuse for inaction." To me, your statements say that we should proceed with caution and not mandate anything until we know that the mandated action will, in fact, solve a problem in a cost-effective manner. Are you suggesting that the Administration's proposal for continued study and incentives for voluntary adoption of technology both here and abroad are an insufficient response given the certainty of the data both with respect to the quantification of the problem and the solution?

Answer. It is important to recognize that U.S. climate policy for more than a decade now has consisted of continued study, technology incentives, and voluntary programs. Progress has been achieved during that decade, to be sure: individual companies made efforts to reduce their emissions, promising new technologies like hybrid vehicles and coal IGCC emerged, and we reached a much better understanding of climate science and of the dynamics underlying potential responses to human-induced changes in the composition of the atmosphere. But the more than 10 years that have passed since the first Bush Administration signed the original International Framework Convention on Climate Change have also demonstrated the limits of voluntarism. Overall, energy-related U.S. greenhouse gas emissions have increased by approximately 12% between 1993 and 2003, the fuel economy of our vehicle fleet has actually declined, and our near-exclusive dependence on fossil fuels in all aspects of our energy system remains as entrenched as ever. Meanwhile, the risks of continuing on our present course have come more clearly into focus than ever before.

In this context, I believe it's important to think carefully about the meaning of caution. Confronted with ever stronger evidence of a potential risk, are we really being cautious to continue increasing our exposure to that risk? Or is it time to do more, albeit cautiously, to reduce this exposure? I would argue that it is indeed time to do more—and by more I mean moving beyond a policy of pure voluntarism. Certainly, the Administration's proposals to promote advanced technologies here and abroad can help. I couldn't agree more strongly that technology investment and increased cooperation with other countries, especially developing countries, are critical components of a sound climate policy. But by themselves they are not enough. For reasons articulated in my responses to several previous questions, it is critical to begin harnessing the power of the marketplace. Simply put, companies need to be able to attach a hard value to avoided carbon emissions if we are going to expect them to make long-term investments in climate-friendly technologies. In a competitive world they will never be able to do that absent a mandatory policy.

NCEP has recommended one approach to implementing such a policy. Moreover, we believe our proposal for a tradable permits system for greenhouse gases is extremely cautious in the sense that it is cost-capped, flexible, gradual, and includes multiple opportunities for review and adjustment. It is so cautious, in fact, that our own analysis and that of the Energy Information Administration indicate it will have no material effect on the U.S. economy over the next decade or more. The specifics of our proposal can certainly be debated; the need for something like it, in my view, cannot. So by all means, let us proceed cautiously. But let us not misunderstand caution to imply that we should merely continue doing what we have been doing, even if that means increasing our exposure to potentially significant climate risks.

Question 2. You suggest that a 5 degree F temperature increase could lead to a whole host of disasters from agriculture losses to drought to melting glaciers and changes in ocean circulations. Do you have evidence of any of this occurring with a 5 degree F increase in temperature, or is this merely speculative? How much of a possible 5 degree F increase in temperature would be attributable to GHGs that are at least nominally under our control? How much of any emission cuts that the U.S. might have to make would simply be overtaken by increases in emissions by developing nations such as China and India?

Answer. While global average temperatures have increased by about 1.5 degrees F since pre-industrial times, the warming that has already occurred over the past few decades in Alaska and the rest of the Arctic is considerably more dramatic (on the order of 3 degrees F). Not surprisingly, Alaska and other northern regions are also providing some of the strongest observable evidence to date of the kinds of impacts that could be associated with warming of this magnitude. As noted in response to a previous question, these impacts include severe coastal erosion due to retreating sea ice, rising sea level, and thawing of coastal permafrost and attendant damage to buildings, roads, and industry. In sum, the proposition that a 5 degree F increase in global average temperatures—which would amount to a three-fold increase in the amount of warming that has already occurred—could cause serious consequences, can hardly be characterized, at this point in time, as "merely speculative."

On the contrary, further warming of this magnitude is likely to greatly amplify many of the negative impacts we are already seeing in Alaska and elsewhere. Temperature changes in the high northern latitudes, which are likely to continue to be more dramatic than the global average, could initiate the rapid deterioration of the Greenland Ice Sheet (which would likely raise the rate of sea level rise to well over 3 feet per century) and cause much further disruption of natural ecosystems, wildlife, and forests. Other consequences in the United States alone could include a significant diminution of spring snowpack in mountain regions, which would greatly exacerbate the chronic water shortages that already exist in the western United States, an increased incidence of serious fires in western forests as well as of extreme weather events, like heavy downpours and heat waves, and declining agricultural productivity in some regions. Meanwhile, impacts in other parts of the world would likely be even worse.

Turning to the issue of international participation, it is of course undeniably true that climate change is a global problem and that efforts to address it will only be successful if every major emitting nation, including developing countries like China and India, takes part. It is, however, equally true that such international cooperation—and particularly the participation of countries like China and India—is unlikely to be forthcoming absent U.S. leadership. As the country with the world's highest emissions, in both absolute and per capita terms, and as the country that is responsible for by far the largest share of the increase in atmospheric greenhouse gas concentrations that has already occurred (and hence for a disproportionate share of the warming to which the planet is already committed), the United States cannot expect other countries to be sympathetic to the argument that it should not act because any domestic emissions reductions it implements might be offset by emissions increases elsewhere. Instead, the United States should set an example and demonstrate its own commitment to addressing the climate problem in a meaningful way, while at the same time making vigorous efforts to engage other nations.

NCEP recommended just such an approach precisely because we felt it was most likely to produce the kind of international participation that will ultimately be vital to mounting an effective global response to the problem of climate change. Given the interest that countries like China and India have in pursuing a more sustainable energy policy—in some cases as much from the standpoint of energy security as out of concern about climate change or environmental quality—we believe there is every reason to be optimistic that a proactive response from the United States would inspire further action to limit emissions by other countries.

Question 3. What if the science showed only a 2-4 degree F increase in temperature by 2100? Would you still advocate mandatory emissions reductions at this time? If so, is the technology available today to accomplish those cuts without raising energy costs?

Answer. Even if the magnitude of predicted warming were somewhat lower than current estimates (e.g., 2-4 degrees F as opposed to 5 degrees F by 2100), the possibility that the actual warming itself and/or its impacts could be more severe than expected—especially if the global climate system responds in non-linear ways as a result of some of the potential feedback mechanisms discussed previously—together with the near certainty that temperatures would continue to rise well into the 22nd century absent some action during the coming decades to reduce emissions, would still, in my opinion, argue for mandatory near-term steps aimed at slowing, then stopping, and eventually reversing current emissions trajectories. The significant impacts that are now being experienced in some places due to the 1.5 degree F increase we have already sustained argue that another 2-4 degrees F would constitute dangerous interference with the climate system, something we have pledged to avoid under the Framework Convention on Climate Change signed by George W.H. Bush.

Given the current status of technology, the Commission believes there is no entirely costless way to achieve this objective: any market signal that attaches a positive value to avoiding greenhouse gas emissions will necessarily produce an increase in the cost of using carbon-producing fossil fuels. It is, however, possible to limit the impact on energy costs to a reasonable and, in our view, politically and socially acceptable level. Specifically, the approach we have proposed (which involves a tradable-permits system for limiting greenhouse gas emissions combined with a safety-valve mechanism that explicitly caps program costs) is estimated to have only a small impact (less than 7% for gasoline, natural gas, and electricity) on predicted energy prices over the next 15 to 20 years. Over time, we believe this market signal will help prompt the innovation and technology investment needed to make further emissions reductions feasible while holding costs and overall energy price impacts to a minimum.

Question 4. In your policy formation statement, you indicate that we should search for a mix of affordable technical and policy measures that will be able to reduce emissions and adapt to the degree of climate change that cannot be avoided without incurring "unreasonable costs." Please define what you mean by unreasonable costs. Do these costs factor in the transfer of industry and jobs to such developing countries as China and India and, if so, do the emission cuts by the U.S. plus the increases by China and India result in a net increase or decrease in emissions?

Answer. The Commission made no attempt to define "unreasonable costs", but we did agree that the explicit cost cap included in our proposal for a mandatory greenhouse gas tradable permits program met the test of reasonableness. Because of the safety valve mechanism in our proposal, we know with certainty that impacts on energy prices for consumers and businesses would be relatively modest (less than 7% for gasoline, natural gas, and electricity). As I have already noted, the Energy Information Administration has concluded that our proposal would have no "material impact" on the nation's economic growth or prosperity between now and 2025. This result rules out the possibility that our proposal could cause any significant transfer of industry and jobs to other countries.

While we are confident that implementing the kind of policy we have recommended will not cause any offsetting emissions increases in China and India, we of course recognize that rapidly growing emissions in these countries must also be addressed if there is to be a meaningful global response to the climate issue. Just as domestic efforts to address climate change will not be successful in the long run absent global participation, however, efforts to engage major developing countries like China and India are unlikely to be successful absent U.S. leadership. The best way to re-establish that leadership, in our view, is for the United States to take an initial step domestically with the understanding that further emissions reduction efforts will be contingent on comparable efforts by other major emitting nations. Accordingly, our proposal is explicitly phased and calls for periodic reviews to assess international as well as domestic progress. Depending on the results of these reviews, the United States could opt to make a variety of adjustments to the tradable permits program, including suspending further increases in the safety valve price. In addition, to encourage emissions mitigation efforts by nations like China and India, the Commission recommends that the United States continue and expand current bilateral negotiations and provide incentives to promote technology transfer and to encourage U.S. companies and organizations to form international partnerships for implementing clean energy projects in developing countries.

Question 5. What is the impact of the U.S. adopting Bingaman/NCEP and China and India not doing so? When the industry and jobs move to China and India, don't global emissions actually go up, as even today, the U.S. has and will continue to have better environmental controls than developing nations? Wouldn't we be better served transferring the technology that we know works to developing nations as they grow in their industry and electricity generation?

Answer. For the reasons described in the previous response, we do not believe that implementation of the Bingaman/NCEP proposal will cause industry and jobs to move to China and India. Moreover, if China and India do not act, we would expect Congress to halt further increases in the safety valve price, thereby allowing the effective stringency of the U.S. program to diminish over time. We think it far more likely, however, that China, India, and other major emitting nations will respond positively if the United States adopts a meaningful, mandatory policy for reducing greenhouse gas emissions. In fact, some of these countries have already begun reducing their emissions below forecast levels as they pursue improved energy security, energy efficiency, conventional pollution control, and market reform. All of these efforts will be enhanced by continued technology transfer from the United States to developing nations which we strongly support as a complement to, rather than substitute for, domestic action.

Question 6. What do you make of the fact that while NOAA concluded that 2004 was the fourth warmest year on record and that some of the warming was human-induced, that satellite instruments (which indirectly measure the average temperature of the atmosphere in a deep column above the surface) are hard pressed to demonstrate any positive trends over the past 20 years?

Answer. This question refers to outdated information about the satellite data based on initial analyses by J. Christy and R. Spenser that have since been corrected. In addition, the rate of warming both at the surface and in the troposphere has increased in the years since that initial analysis.

Recent peer-reviewed analyses of the satellite data have shown that the low and mid troposphere have in fact warmed at about the same rate as the surface over the past several decades (see e.g., Mears et al., 2003; Vinnokov and Grody, 2003; Vinnikov et al., 2004).[9] The earlier notion that the troposphere had not warmed was based on significant errors in adjustments to the satellite data. As each error was corrected, the data showed more warming. Studies published this month (11 August 2005) in Science expose the most recently discovered of these errors.[10]

Though there are minor discrepancies between data sets due to the different methods that research teams use to analyze the data, the bottom line is that both the surface and the troposphere show significant warming trends according to all the data records: those derived from thermometers at the surface, those derived from sensors on satellites, and those obtained from weather balloons. There is no major difference between surface and tropospheric warming at the global scale over the past 50 years.

Question 7. If all the countries that have signed Kyoto stay within compliance of Kyoto, how much of a reduction in global warming would this result in?

Answer. The Kyoto Protocol never represented more than a first step toward addressing the climate problem at a global level—indeed it sought to define only relatively near-term (2008-2012) emissions targets. As such, it was not designed to, by itself, achieve the sustained, overall emissions reductions that would be necessary to prevent or substantially mitigate expected changes to the Earth's climate as a result of increased atmospheric concentrations of greenhouse gases. Rather, the argument for ratifying Kyoto (which has now been done by nearly all of the United States' major industrialized trading partners) always rested on the proposition that it was important for the developed countries to lead the way in starting to curb future emissions, even if it was understood that these early efforts would have little effect in and of themselves unless they were followed up in the post Kyoto era by a more comprehensive global effort.

I and other members of NCEP essentially share the conviction that near-term, mandatory action and leadership by developed nations like the United States are necessary to begin making progress on the climate issue. We also believe, however, that we have crafted an approach that is preferable to Kyoto insofar as it convincingly addresses the cost, equity, and competitiveness concerns that have been raised in connection with Kyoto. In any case, all sides in the ongoing domestic and international debate over future climate policy should be able to agree that the time for debating the merits of the Kyoto Protocol is past. That debate is now largely moot and prolonging it only serves those whose interests lie in continued policy paralysis and delay.

Question 8. Can you confirm that suspended water vapor levels, cloud cover percentages and direct solar irradiation changes over time all represent variables in these forecasting models that could have significant impacts on the conclusions of the results of these models?

Answer. Certainly all of these variables have a significant impact on the Earth's climate system and on the predictions generated by existing climate models. Accordingly, our ability to accurately incorporate these (and many other) variables in our models is constantly being refined and compared to actual observations. While uncertainties remain in specific areas, however, our overall confidence in existing climate models is bolstered by several factors. First, as noted in my response to a previous question, current models can replicate past and present climates as well as the influences of the most important factors that affect climate. Second, a variety

[9] See, for example, Mears, C.A., M.C. Schabel, and F.J. Wentz, 2003: A Reanalysis of he MSU channel 2 tropospheric temperature record. *J. Climate*, 16, 3650-3664; Vinnikov, K.Y., and N.C. Grody, 2003: Global warming trend of mean tropospheric temperature observed by satellites. *Science*, 302, 269-272; and Vinnikov, K.Y., A. Robock, N.C. Grody, and A. Basist, 2004: Analysis of diurnal and seasonal cycles and trends in climatic records with arbitrary observation times. *Geophys. Res. Lett.*, 31, L06205, doi:10.1029/2003GL019196, 2004.

[10] Mears, C.A., and F.J. Wentz, *Science*, 2005: The effect of diurnal correction on satellite-derived lower tropospheric temperature. 11 Aug 2005.

of models, all of which have been extensively compared, tested, and refined, provide essentially coherent and consistent results concerning the likely impacts of anticipated changes in the composition of the Earth's atmosphere. Thus while different models may treat individual variables such as those identified above somewhat differently, the fact that they nevertheless come to substantially similar conclusions suggests that we can have a high degree of confidence in their overall results.

Question 9. In looking at pre-industrial global temperature patterns, would you agree that changes in temperatures over time have occurred that had no anthropogenic basis?

Answer. It is of course true that changes in global temperatures occurred before human activities had any significant impact. Scientists who study past climates have been able to identify the likely causes of most of those changes and have determined that the warming trend observed in global average temperatures over the last 50 years is strikingly different from past changes and can only be explained by including human influences in the calculus. In fact, the IPCC has concluded that human activities not only play a role, but are primarily responsible for this trend. Two points are relevant here. The first is that as noted repeatedly in response to previous questions—it is the pace of anticipated climate change, as much as the potential magnitude of this change, that we should be worried about. Compared to past climate changes that occurred as a result of purely natural influences, human-induced climate change appears to be progressing at a rate that is simply unmatched in recent geological time. Second, the fact that climate change can also occur absent human influence does not lead logically to a justification for complacency. One might as well argue that because wildfires can also be caused by lightning, people should feel free to toss lit matches into the forest.

Question 10. Do we know what the "best" global temperature is to sustain life?

Answer. The most general answer to this question is that there is no single "best" temperature for sustaining life on Earth. At any given temperature, different organisms and ecosystems will evolve toward a different equilibrium than they would at any other temperature and it is fundamentally impossible to single out any one of these states as definitively "better" than any other. More than any particular temperature, however, it is possible to say that climatic *stability* is important to sustaining life. Dramatic and rapid changes in climate are almost always detrimental, both to individual organisms and to the larger ecosystems they inhabit.

To attempt a more specific answer to this question, one would have to start by specifying what type of life one is interested in sustaining. Insects and weeds, for example, tend to do very well in a warmer world (as evidenced by the recent massive increase in spruce bark beetle outbreaks and the observed doubling of ragweed pollen production). On the other hand, some species, like the golden toad that used to inhabit the cloud forest of Costa Rica, have already been driven to extinction by the warming that has already occurred over the past 50 years. Other species, like the polar bear and ice-dependent seals, are increasingly stressed and may find it more and more difficult to survive in the wild as continued warming further shrinks the summer sea ice on which they depend. Coral reef ecosystems, the nursery for many marine species, are also at risk of succumbing to warmer temperatures and the changing chemistry of ocean water due to rising atmospheric CO_2 levels. Many other life forms that cannot adapt or relocate quickly are similarly threatened by rapid, human-induced climate change.

Assuming that the priority for most policymakers would be to preserve optimal conditions for human life, it remains difficult to identify a single "ideal" temperature. Here again, however, the more relevant point is that human societies and infrastructure the world over have developed in climatic conditions that have been remarkably stable for 10,000 years. As a result, the assumption that these conditions will continue is "built into" most aspects of our existence, whether we live in highly industrialized societies or in societies that are more directly dependent on natural systems for shelter and sustenance. A rapidly changing climate could therefore impinge on human existence and quality of life in a wide variety of ways. At best, the consequences will frequently be costly and inconvenient; at worst they could cause significant loss of life and higher rates of injury and disease.

To give just one example, many of the world's coastlines have become heavily populated under the implicit assumption that sea level would be relatively stable. But global warming is already causing sea levels to rise and is likely resulting in higher storm surges, more coastal erosion, and a marked increase in the destructive power of hurricanes.[11] If these trends continue, the consequences in wealthier countries like the United States could include substantial property losses and high costs to move housing and infrastructure as populations are forced to relocate further inland. In poorer and more vulnerable low-lying countries like Bangladesh, the results would likely be more dire and could include significant loss of life, increased incidence of disease, and massive population displacements.

Question 11. What is currently being done to curb emissions from parts of the world in poverty who are deforesting their environment and burning biomass for all means of day-to-day living, and are these emissions continuing to increase in the world?

Answer. Developing nations have as much reason as developed nations to be concerned about climate change and as much incentive to reduce their greenhouse gas emissions, given that they are likely to be especially vulnerable to the negative impacts of future warming. What they lack, in many cases, are the economic and institutional resources to implement policies for reducing emissions, as well as access to the technologies that would make it possible to pursue their legitimate aspirations for development in a more environmentally sustainable manner. This situation speaks to the need for a continued emphasis on technology transfer and assistance from developed countries to the developing world to overcome these obstacles. At the same time, it must be emphasized that many developing countries are already making concerted efforts to address environmental and public health concerns in ways that will also yield ancillary benefits in terms of reduced greenhouse gas emissions. Examples include efforts to reduce methane emissions from sewage and garbage (these emissions can be comparatively large in many developing countries), to address a major public health concern by reducing soot emissions from inefficient cooking stoves and 2-stroke engines, and to limit deforestation and restore vegetation cover as means of controlling erosion and improving water quality. In some cases, developing countries have even moved ahead of developed countries with respect to adopting progressive environmental or energy policies. China, for instance, recently moved to implement tougher automobile fuel economy requirements than currently exist in the United States.

Question 12. Do you believe it is practical to seek emission controls in parts of the world that are struggling in poverty?

Answer. With assistance and access to improved technologies, it is not only practical but essential for many poor nations to pursue a development path that is cleaner, more sustainable, and less carbon-intensive than the development path traveled by already wealthy, industrialized nations. I believe it is the responsibility of developed nations to help make this possible.

Question 13. What is being done to curb emissions in the developing countries like China and India?

Answer. See question 11 above.

RESPONSES OF DR. MARIO MOLINA TO QUESTIONS FROM SENATOR FEINSTEIN

Question 1. Is there any credible scenario for stabilizing greenhouse gas emissions that does not involve the United States and other major emitters stopping their emissions growth over the next couple of decades and sharply reversing their emissions growth by 2050?

Answer. No. To stabilize atmospheric greenhouse gas concentrations during this century, total global emissions—including emissions from the United States and all other major emitting nations—must begin to decline at some point in the coming decades. The steepness of this decline or—as you put it the sharpness of the reversal, depends on the stabilization target being pursued and on when the decline commences. For example, one estimate published by Wigley, Richels, and Edmonds in 1996 indicates that global emissions must begin to turn down beginning in 2035 in order to achieve the goal of stabilizing atmospheric CO_2 concentrations at 550 ppm by the end of the century. By the same token, slowing the rate of emissions growth in the near term will allow the eventual decline needed to achieve a given stabilization target to be more gradual and/or to commence at a later point in time.

Question 2. Would the National Commission on Energy Policy's proposal stop and then reverse U.S. greenhouse gas emissions?

Answer. The NCEP proposal lays out a specific approach for achieving the slow and stop phases of a program to reduce U.S. greenhouse gas emissions. The slow

[11] For example, Emanuel (2005) has documented a marked increase in the destructive power of hurricanes over the past 30 years as these storms have become, on average, more intense and of longer duration (Emanuel, Kerry, 2005, *Nature*, 4 August 2005, Vol. 436/4, Increasing destructiveness of tropical cyclones over the past 30 years.).

phase covers the first decade of program implementation (from 2010 through 2019); the stop phase is initiated starting in 2020. Put another way, the NCEP recommendations take us to the year 2020 on the below graphic and not beyond. We consciously chose not to detail the terms of the "reverse" phase, recognizing that it would be presumptuous and probably meaningless to presuppose the likely evolution of an intentionally flexible and contingent program more than two decades into the future. That said, it is important to point out that the architecture of our proposed policy would readily support the implementation of a reverse phase designed to steadily reduce U.S. emissions.*

As our report states, the NCEP proposal " should be understood as an initial domestic step in the long-term global effort to first slow, then stop and ultimately reverse current emission trends. In its structure and stringency, the Commission's proposal is designed to encourage the timely initiation of what will necessarily be a phased process. The Commission believes that this approach is more pragmatic and ultimately more effective than years of further legislative stalemate in pursuit of a more aggressive initial goal."

Put simply, we believe that the accumulated emissions resulting from additional years of inaction are almost sure to be greater than the possible benefits that would result from postponing more aggressive action to a point in the more distant future. Once a market signal is in place, we expect that solutions will flourish, anxieties will abate, and Congress will be better able to predict and then adopt more stringent iterative emissions reduction requirements.

RESPONSES OF RICHARD D. MORGENSTERN TO QUESTIONS FROM SENATOR BINGAMAN

Question 1. Questions have been raised about the uncertainties for potential investors in new refineries or other energy facilities that could be created by the provision in the Bingaman amendment that calls for Congress to review emissions goals, price caps, and other features every five years. Could you comment on this?

Answer. My understanding is that this provision gives Congress an opportunity to evaluate new information such as the actions of other nations or new scientific, technological, or economic developments that might affect future emissions goals, price caps, or other design elements of the program. It seems quite consistent with the routine Congressional reviews conducted in other policy areas. The uncertainties inherent in future energy markets, climate science, and prospect of future climate policies of one kind or another—with or without adoption of the Bingaman amendment—are likely to dominate any economic or financial assessment of refineries or other energy facilities.

Question 2. Do I correctly understand that the so-called safety valve or cost cap provisions in the National Commission on Energy Policy proposal and Bingaman legislation provide for economic certainty, but not environmental certainty. Can you explain how that works?

Answer. The safety valve or price cap is, in effect, a type of insurance policy designed to protect the economy against unexpected price increases caused by weather, stronger than predicted economic growth, technology failures, or other factors. Despite the success of the cap and trade provision in the acid rain program, which lacks a safety valve, problems have arisen in other programs. For example, during the California energy crisis the price of nitrogen oxide (NO_X) permits rose to $80,000 and, more recently, in the early phase of the EU trading system, prices have fluctuated between 8-30 Euros for carbon dioxide (CO_2) permits.

Differences among forecasters have plagued previous policy proposals to reduce GHGs. President Clinton's Council of Economic Advisers forecasted allowance prices below $8/ton of CO_2 compared to the Energy Information Administration's (EIA) estimate of $43. With a safety valve, emissions estimates may vary but costs cannot rise above the established price cap. Recent EIA sensitivity analyses confirm this point, as they found compliance costs to be virtually invariant with respect to a wide range of assumptions about natural gas supplies, the availability of non-carbon offsets, and other factors.

The safety valve differs in a few important respects from a well-known provision in the 1990 Clean Air Act Amendments that establishes a $2,000-per-ton penalty (1990$) for violations of the stipulated sulphur dioxide (SO_2) emissions standards. Since the Clean Air Act penalty is far above the expected marginal control cost, it has a very low probability of being invoked. In contrast, the proposed safety valve price reflects the society's willingness to pay for carbon mitigation and is not in-

* The accompanying graphic has been retained in committee files.

tended strictly as a punitive measure. For those who believe that the costs of reducing greenhouse gas emissions are relatively low, permit prices would never reach the trigger level and emissions would remain capped.

Question 3. Emission trading programs have been highly successful in phasing out leaded gasoline and CFCs, and most notably in reducing emissions of S02 and NO_X through the Acid Rain trading program. Is emission trading a good policy instrument for addressing climate change? Why or why not?

Answer. I believe that a market mechanism like emissions trading is an excellent policy tool for addressing climate change. Introduction of an emissions trading program would have two distinct effects. It would create incentives to reduce emissions in the near term, thus mitigating environmental damages associated with those emissions. And, at the same time, it would alter incentives for the private sector to develop and adopt new technologies. While these same effects would occur under a carbon tax regime as well, an emissions trading system does not oblige the private sector to make payments directly to the government and, correspondingly, obviates the need of the government to make decisions about how best to recycle the funds. As noted in the response to question two, inclusion of a safety valve would protect the economy against unexpected price increases caused by weather, stronger-than-predicted economic growth, technology failures, or other factors.

Question 4. The United States spends a significant amount of money on R&D into non-carbon and low-carbon technologies. How does this amount compare to our overall economy, our total spending on energy, and our total greenhouse gas emissions? Are other countries spending comparable amounts based on their size and emission levels?

Answer. Various U.S. and foreign government agencies report information relevant to this question. In the following paragraphs, I have summarized the most relevant and recent information and also provided references for future follow-up.

For each of the past three years, the U.S. Office of Management and Budget (OMB) has issued a report to Congress entitled *Federal Climate Change Expenditures*, which details federal spending on programs and tax proposals related to climate change. Table 1 provides a summary of spending for these programs from 2002 through 2006. The proposed 2006 budget indicates that approximately $4.7 billion will be spent on R&D (this number was calculated by adding the total budgets for the Climate Change Science and Technology Programs. Table 1 also shows that over the past few years total spending on the Climate Change Science Program has decreased slightly. In addition for the 2006 fiscal year, there is a small reduction in spending is proposed in the Climate Change Technology Program, relative to the enacted 2005 budget. Overall, federal climate change expenditures have increased, but this is largely due to the increase in spending on energy tax incentive proposals (For further information about the breakdown of climate change spending, by department, see Appendix B of OMB 2005).

Table 1.—SUMMARY OF FEDERAL CLIMATE CHANGE EXPENDITURES ON PROGRAMS AND TAX PROPOSALS RELATED TO CLIMATE CHANGE, FY 2006 PRESIDENT'S BUDGET

[Discretionary budget authority and tax proposals in millions of dollars]

	FY 2002 Actual	FY 2003 Enacted	FY 2004 Actual	FY 2005 Enacted	FY 2006 Proposed	$ Change 2006-2005
Climate Change Science Program (CCSP)						
U.S. Global Change Research Program	1,667	1,722	1,803	1,700	1,711	11
Climate Change Research Initiative		42	173	217	181	−36
Subtotal—CCSP[1]	1,667	1,764	1,976	1,918	1,892	−26
Climate Change Technology Program (CCTP)						
Department of Agriculture	3	39	45	48	35	−13
Department of Commerce			28	30	7	−22
Department of Defense			51	75	60	−15
Department of Energy	1,519	1,583	2,390	2,505	2,506	1
Department of the Interior			1	2	2	0
Department of Transportation			5	1	2	1
Environmental Protection Agency	115	106	110	109	113	4
National Aeronautics and Space Administration			227	208	128	−80

Table 1.—SUMMARY OF FEDERAL CLIMATE CHANGE EXPENDITURES ON PROGRAMS AND TAX PROPOSALS RELATED TO CLIMATE CHANGE, FY 2006 PRESIDENT'S BUDGET—Continued

[Discretionary budget authority and tax proposals in millions of dollars]

	FY 2002 Actual	FY 2003 Enacted	FY 2004 Actual	FY 2005 Enacted	FY 2006 Proposed	$ Change 2006-2005
National Science Foundation			11	11	11	1
Subtotal—CCTP[1]	1,637	1,728	2,868	2,989	2,865	−124
International Assistance						
U.S. Agency for International Development	174	214	195	189	162	−27
Department of State	7	6	5	6	11	5
Department of the Treasury[2]	43	56	52	45	25	−20
Subtotal International Assistance	224	276	252	240	198	−42
Energy Tax Incentive Proposals That Reduce Greenhouse Gases[3]	0	0	0	83	524	441
Total[1 4]	3,522	3,762	5,090	5,223	5,473	250

[1] Subtotals and table total may not add due to rounding. Subtotals and totals supersede numbers released with the President's 2006 Budget. Discrepancies resulted from rounding and improved estimates.

[2] The FY 2004 and FY 2005 enacted level for the Tropical Forestry Conservation Act (TFCA) is $20 million each year. In FY 2006, the Administration has requested a total of $99.8 million for debt restructuring programs to be available for: bilateral Heavily Indebted Poor Countries (HIPC) and poorest country debt reduction, contributions to the HIPC Trust Fund, and TFCA debt reduction. The Budget provides the Treasury Department flexibility in determining the amount for each program. The FY 2006 funding level for TFCA has not been determined yet.

[3] The cost of the four energy tax incentives related to climate change included in the President's FY 2006 Budget is $3.6 billion over five years (2006-2010).

[4] The International Assistance subtotal contains funds that are also counted in the Climate Change Science Program subtotal. Table total line excludes this double-count.

Source: Adapted from OMB 2003, and 2005.

In its *Annual Energy Review* EIA provides information on energy consumption, energy expenditure, and emissions in relation to GDP. The most recent EIA calculations on energy expenditures show that in 2001 the United States spent $693.6 billion on energy (nominal dollars, EIA 2004). This amount was 6.8 percent of the GDP that year (ETA 2004). In 2002, OMB reports that $3.3 billion was spent on the Climate Change Science and Technology programs, which is 0.03 percent of the 2002 GDP (ETA 2004; OMB 2003).

Greenhouse gas emissions were estimated to be 6,828.9 million metric tons of carbon dioxide equivalents in 2001 and 6,862.0 million metric tons of carbon dioxide equivalents in 2002, an increase of 0.5 percent (EIA 2003). EIA also provides estimates of greenhouse gas emissions relative to GDP. In 2001, greenhouse gas emissions were 691 metric tons of carbon dioxide equivalent per million (2000 chained) dollars (EIA 2004). In 2002, this number decreased to 684 metric tons of carbon dioxide equivalent per million (2000 chained) dollars (EIA 2004).

While I am more familiar with U.S. spending and greenhouse gas data, I was able to find some information on foreign spending on climate change and greenhouse gas emissions. The European Environment Agency (EEA) reported that the EU-15 emitted 4,180 million metric tons of CO_2 equivalents in 2003 (EEA 2005). Table 2 provides the breakdown of emissions by country. EEA also reported that it spent 831,000 Euros, or $ 934,758 (converted using OECD's Purchasing Power Parity for 2004) on "tackling climate change" in 2004 (EEA 2004).

Britain's Department for Environment, Food, and Rural Affairs reports that the government funded an λ11.5 million research program in 2000-2001 in order "to improve . . . understanding of the science and impacts of climate change, to quantify the UK's emissions of greenhouse gases, and to inform policies on reducing emissions" (DEFRA 2001). This amount is equal to approximately $18.5 million (2001 dollars, converted using Purchasing Power Parity).

A list of sources is presented below:

DEFRA. 2001. *Climate Change UK Programme*. Available at *http://www.defra.gov.uk/environment/climatechange/cm4913/4913html/index.htm.* Last accessed Oct. 2005.

EEA. 2004. *Annual Report 2004*. Available at *http://reports.eea.eu.int/report__2004__0622__154840/en/Annual-report-FINAL__web.pdf*. Last accessed Oct. 2005.

EEA. 2005. *European Community Greenhouse Gas Emission Trends.* Available at *http://reports.eea.eu.int/technical__report__2005__4/en/EC__GHG__Inventory__report__2005.pdf*. Last accessed Oct. 2005.

EIA. 2003. *Emissions of Greenhouse Gases in the United States 2002*. Report #: DOE/EIA-0573(2002/ES). Available at *http://www.eia.doe.gov/oiaf/1605/gg03rpt/summary/index.html*. Last accessed Oct. 2005.

EIA. 2004. *Annual Energy Review* 2004, Report No. DOE/EIA-0384(2004). Available at *http://www.eia.doe.gov/emeu/aer/contents.html*. Last accessed Oct. 2005. (Table available at *http://www.eia.doe.gov/emeu/aer/txt/ptb0105.html*)

OECD. 2005. Purchasing Power Parities. Available at *www.oecd.org/dataoecd/61/54/18598754.pdf*. Last accessed Oct. 2005.

OMB. 2003. *Federal Climate Change Expenditures, Report to Congress.* Available at *http://www.whitehouse.gov/omb/legislative/fy04__climate__chg__rpt.pdf*. Last accessed Oct. 2005

OMB. 2005. *Federal Climate Change Expenditures, Report to Congress.* Available at *http://www.whitehouse.gov/omb/legislative/fy06__climate__change__rpt.pdf*. Last accessed Oct. 2005

Table 2.—OVERVIEW OF MEMBER STATES' CONTRIBUTIONS TO EC GHG EMISSIONS EXCLUDING LUCF FROM 1990 TO 2003 IN CO_2 EQUIVALENTS (TG)

Member State	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Austria	79	83	76	76	77	80	83	83	83	80	81	85	86	92
Belgium	146	149	147	146	151	152	157	148	153	146	148	147	145	148
Cyprus	6	6	7	7	7	7	8	8	8	8	9	8	9	9
Czech Republic	192	178	164	158	152	153	155	159	149	140	148	148	143	145
Denmark	69	80	74	76	80	77	90	80	76	73	68	70	69	74
Estonia	43	41	30	23	24	22	23	24	22	20	20	19	20	21
Finland	70	69	67	68	74	71	77	76	73	72	70	76	77	86
France	568	593	585	559	555	563	578	572	584	566	560	564	554	557
Germany	1,244	1,191	1,142	1,126	1,108	1,103	1,121	1,084	1,057	1,021	1,017	1,028	1,015	1,018
Greece	109	109	110	110	113	114	118	123	128	127	132	134	134	138
Hungary	103	95	85	85	85	84	86	84	84	84	81	84	81	83
Ireland	54	55	56	56	57	58	60	63	65	67	69	71	69	68
Italy	511	513	509	505	496	528	519	525	535	544	551	556	555	570
Latvia	25	24	19	16	15	12	12	12	11	10	10	11	11	11
Lithuania	51	45	42	38	35	31	28	24	22	21	21	20	20	17
Luxembourg	13	13	13	13	13	10	10	9	8	9	10	10	11	11
Malta	2	2	3	3	3	3	3	3	3	3	3	3	3	3
Netherlands	212	216	215	221	221	224	233	225	227	215	214	216	213	215
Poland	460	438	440	430	440	417	437	427	404	402	386	383	370	384
Portugal	59	61	65	64	65	70	67	70	75	83	80	81	86	81
Slovakia	72	63	59	55	52	53	54	54	52	51	48	53	52	52
Slovenia	19	17	17	18	18	19	19	20	20	19	19	20	20	20
Spain	284	290	299	287	303	315	307	328	337	365	380	379	399	402
Sweden	72	72	72	72	75	73	77	73	73	70	67	68	69	71
United Kingdom	748	752	729	710	700	691	714	691	686	652	652	663	644	651
EU-25	5,212	5,156	5,023	4,919	4,917	4,931	5,036	4,964	4,935	4,849	4,844	4,894	4,852	4,925
EU-15	4,238	4,246	4,159	4,087	4,088	4,129	4,211	4,150	4,160	4,091	4,100	4,146	4,126	4,180

Source: EEA 2005

Question 5. You seem to agree that the most important long-term feature of any climate policy is the impact it will have on investment in R&D and the development of new, carbon-free technologies in both the private and public sectors. What do you believe are the best policies for pursuing needed R&D? Should these R&D initiatives be primarily taxpayer funded, government R&D programs, or should we pursue policies to provide incentives for private-sector R&D?

Answer. Few would disagree that the private sector, not the government, has driven innovation and growth in the modern economy. For example, according to the National Science Foundation, in 2003 industry (not government) funded almost two-thirds of all R&D in the United States.

It is also widely recognized that government has an important role to play in spurring the development and diffusion of these technologies. Without some kind of additional incentives, the private sector typically will under-invest in research, development, and demonstration because innovators cannot reap the full benefits to society of their advances. The existence of these "spillovers" reduces private incentive to pursue innovation, as others will mimic the innovation without compensating the inventors. While patents and similar means are used to protect investments in innovation, that protection is limited. A successful innovator typically captures substantial rewards, but those gains are sometimes only a fraction of the total benefits to society arising from the innovation. This rationale underlies government support of research, development, and demonstration programs, including the National Science Foundation, public universities, and other research institutions.

Environmental and knowledge externalities have long been at the center of debates about technology policy. More recently, we have come to understand some additional market failures that may operate in the adoption and diffusion of new technologies. For a variety of reasons, the cost or value of a new technology to one user may depend on how many other users have adopted the technology. Generally speaking, users will be better off the more others use that same technology, as this increases what is known as "learning by doing" and "network" externalities. Typically, it takes time for potential users to learn of a new technology, try it, adapt it to their particular circumstances, and become convinced of its superiority. Consequently, the early adopter of a new technology creates a positive benefit for others by generating information about the existence, characteristics, and likely success of the new technology.

The argument for public support is even stronger in the case of climate change technologies, where not only do inventors fail to capture all the gains from their investments but the gains themselves are not fully translated to the firms' bottom line because there is no market value associated with emissions reductions. Further, the prospect of future value—which is driven by policy outcomes—is uncertain.

Absent government incentives, corporate concern for the environment may overcome some hurdles. Working against this kind of "corporate altruism," however, is the need to compete in the marketplace. A company that puts meaningful effort into reducing greenhouse gas emissions, rather than reducing costs, may eventually lose out to one that only seeks to reduce costs.

It is exactly this need to align public and private interests that underlies the argument for an emissions trading program, or similar mechanism, alongside technology development and demonstration programs. While the government seeks technologies to cut carbon emissions, the private sector seeks technologies to cut costs. Market-based policies that put a value on emissions reductions encourage firms to conserve energy, reduce emissions from existing technologies, and adopt new low-carbon or no-carbon technologies. In contrast, policies that only focus on technology adoption fail to take advantage of reductions that could come from existing technologies and conservation.

Question 6. Roughly how large an R&D investment do you believe is needed at this time, given that radically new technologies will be required in the future to address climate change? Are current energy R&D funding levels adequate, or do you think additional resources are required?

Answer. It is difficult to judge the "optimal" funding level for R&D. As noted in the response to question number 4, OMB reports proposed 2006 budgets for climate change science and climate change technology of $1,892 and $2,865, respectively. The NCEP proposal would approximately double the spending levels on the climate change technology program over a 10-year period. While still higher levels may be justified, an equally important issue concerns the mechanism used to fund the R&D. Recognizing that funding of R&D has a somewhat checkered past, due partly to a large (and growing) degree of congressional earmarking and annual funding fluctuations, it is important that the designated funds be subject to an independent, multiyear, integrated planning process. Ideally, an independent group or commission assembled for this purpose would have, as its goal, the best allocation of R&D

funds for long-term, cost-effective climate mitigation and would include experts from government, private industry, and academia.[1]

Question 7. What are the advantages and disadvantages of using intensity-based emission targets?

Emissions intensity targets focus on emissions per dollar of real GDP, rather than on the absolute level of emissions. In my view, a key advantage of intensity-based targets is that they help shift the debate away from measuring progress strictly in terms of zero or negative growth in emissions as a near-term goal, which is an unrealistic objective for a growing economy like that of the United States. In contrast, emissions-intensity frameworks start out with the more achievable goal of slowing the rate of emissions growth. Especially as nations are just beginning to implement mandatory emission reduction programs, such a formulation is more pragmatic. Another advantage of intensity targets is that they promote an emphasis on progress rather than simply on the absolute status of one nation versus another, which could help ease some of the concerns about equity among nations. A further advantage of intensity-based targets is that developing nations often appear favorably in such calculations as they are reaping the natural declines arising from modernization. This could facilitate the entry of developing nations into meaningful initial commitments.

That said, intensity targets also have a number of disadvantages. First, they are harder to convey to the public than a simple emission cap. Second, the main advantage of intensity targets—that they do not draw attention to zero growth as a benchmark for progress—will be seen as a disadvantage by advocates who seek such a benchmark.

A final observation is that intensity targets are not a useful way to deal with economic shocks that make the cost of any emission limit uncertain. Other mechanisms, such as safety valves, can better address this problem, as discussed in the response to question 3. A fuller discussion of intensity targets can be found in a recent paper by my RFF colleague, William Pizer.[2]

Question 8. What are your views on setting up a trust fund with the proceeds from a cap and trade program and using the revenue to fund investment in low-emission energy technologies?

Answer. While trust funds are sometimes pilloried as “lock boxes” that distort national spending priorities, the requirements of science and technology programs for long-term, stable funding mitigates against such concerns. The fact that the revenues for the trust fund would be derived from hitherto-untapped sources closely tied to the goals of the R&D programs also addresses these concerns. On balance, I think there is a good case for setting up a trust fund with the proceeds from a cap and trade program and using the revenue to fund investment in low-emission energy technologies.

Question 9. Please comment on your view of success of EU program and what we can learn as we move forward in the United States.

Answer. The European Union Emissions Trading System (EU-ETS) is a major environmental policy, representing the world’s first large-scale greenhouse gas trading program. It covers more than 11,000 facilities in 25 countries and 6 major industrial sectors. The first stage of the program is now in operation, covering CO_2 emissions only. National allocation plans have been approved in all nations, although registries in all nations are not yet fully operational. Protocols have been established for uniform monitoring of emissions. Allowances equal to monitored emissions must be surrendered on an annual basis, beginning at the end of this year. Beginning in 2008, the system will be expanded to include additional sectors and additional greenhouse gases. Significant trading volumes are already occurring, mostly in the power sector, and the system seems poised to deliver real but modest reductions compared to a business-as-usual scenario. Possible lessons for the United States can be drawn from the early experiences of the EU-ETS:

- The price of allowances has fluctuated considerably (8-29 Euros) since the beginning of the program in January 2005. Some of the fluctuations are clearly associated with weather and fuel-price dynamics. Many observers believe that over the longer term prices will decline as the early growing pains of the program are resolved and, particularly, as more eastern European nations establish registries and enter the market more actively. Had the EU-ETS adopted

[1] For further discussion of how this process might work, see Kopp, Raymond J., Richard D. Morgenstern, Richard G. Newell and William A. Pizer, “Stimulating Technology to Slow Climate Change,” in *New Approaches on Energy and the Environment*, (Morgenstern and Portney, editors), RFF Press, 2004.

[2] Pizer, William 2000. “The Case for Intensity Targets,” Discussion Paper 05-02, Resources for the Future, Washington, D.C. (forthcoming in *Climate Policy*).

a safety valve at a level consistent with the long-term price expectation, as has been widely discussed in the United States, some of the extreme price fluctuations would have been avoided.

- The EU-ETS covers less than 50 percent of the total EU emissions; consequently, the success of the trading program does not imply that the EU will meet its overall emissions targets under the Kyoto Protocol. Rather, achievement of the Kyoto target depends partly on the success of various regulatory and voluntary programs in place in other sectors of the economy, plus the success of governments in purchasing allowances from Russia or other Annex B nations, or through the Clean Development Mechanism. Recent discussions in the United States have focused on economy-wide or near economy-wide systems that, by definition, would not have the same type of problems.
- Because the EU-ETS is based on the operation of a series of national-based institutions throughout the EU, problems in individual nations can affect the prices and availability of allowances elsewhere. The fact that the registries in some nations are not yet operational, particularly in Eastern Europe where net selling is expected, means that the market remains thin and sensitive to single trades. The same problems are not likely to occur in the United States, where discussions have focused on a market entirely organized at the national level.

Question 10. It is sometime said that using a safety valve is the same as adopting a carbon tax. Please explain why you agree or disagree.

Answer. Some, in opposing a safety valve try to smear it by calling it a disguised tax. In this regard, I would make two points: first, if the price cap level is not reached, then it is strictly a cap-and-trade mechanism, just like the acid rain program and not at all like a tax. Second, even if the price cap level is reached, only a small portion of the revenues would accrue to the government, in this case to fund research and development. The bulk of the revenues would flow directly back to the private sector. Because a tax is principally defined in terms of the revenues it generates, and since only a small portion of the revenues ever end up in the hands of the government, it is not accurate to describe the safety valve as a tax.

RESPONSES OF RICHARD D. MORGENSTERN TO QUESTIONS FROM SENATOR AKAKA

Question 1. I have some questions about the carbon-trading program in the European Union.

- We know that Europe has started a carbon-trading program. Can you please describe the basics of what is happening there? How is the carbon traded, capital generated, and who receives the benefits?
- Second, what is the outlook for success in this trading program?
- Finally, what are the lessons for the U.S. from Europe's experience? Has there been widespread unemployment or lack of economic growth?

Answer. Please see the answers to Senator Bingaman's question number 9.

Question 2. From your testimony, it sounds like the National Commission on Energy Policy proposal would have a very small impact on the U.S. economy overall. Further, it will not "avert" climate change over the next 20 years. However, you apparently believe that it is very important to undertake something like the NCEP proposal. Can you explain a little more why it is so important if we aren't having an effect on climate change?

Answer. The principal reason that NCEP's approach would have a much smaller impact on the U.S. economy than the Kyoto Protocol or S. 139 is that, fundamentally it is not designed to avert climate change over the next 20 years. Rather, the focus is on developing and deploying technologies needed to address the problem in the decades beyond. The NCEP proposal does this primarily in two ways: 1) by directly subsidizing a wide range of new technologies including coal, nuclear, fuel-efficient vehicles, biofuels, and others; and 2) by encouraging private-sector research and development through incentives for the deployment of cost-effective carbon saving technologies of all types. NCEP's cap-and-trade system has the added benefit of generating a revenue stream to fund the technology subsidies.

The NCEP strategy recognizes that large-scale emission reductions in the near term are not a prerequisite to long-term success of the overall mitigation strategy. Unlike SO_2, lead, or other pollutants with short-term health impacts, the damages associated with climate change are primarily long term in nature. The mitigation strategy used to address the issue needs to reflect that understanding of the problem.

RESPONSES OF RICHARD D. MORGENSTERN TO QUESTIONS FROM SENATOR FEINSTEIN

Question 1. Under the National Commission on Energy Policy's proposal, what happens when a covered entity uses the safety valve rather than lowering emissions? What is done to ensure that emissions are actually reduced?

Answer. An economic-based measure such as a cap-and-trade system provides incentives for industry, consumers, and governments to reduce their emissions. Such incentives have been proven successful in the SO_2 trading program and elsewhere in the United States and abroad. A safety valve is designed to protect the economy against unexpected price increases caused by weather, stronger than predicted economic growth, technology failures, or other factors.

If the goal is to reduce emissions in the near term without regard for the economic consequences, then a safety valve is not necessary. However, if the goal is to address the long-term build up of greenhouse gases in the atmosphere without imposing undue economic harm, then the safety valve is an appropriate mechanism.

Question 2. Under the Commission's proposal, a company could pay the $7/ton fee instead of reducing the greenhouse gases. So, in the end, is there really a firm cap on emissions?

Answer. The $7/ton charge creates incentives for all sources to undertake emission reductions up to the point where mitigation costs reach that level. With such a scheme in place, more expensive mitigation activities would not likely be undertaken.

Question 3. What policy solutions do you recommend to correct for this so we can still make environmental progress?

Answer. The answer depends in large part on how one defines "progress." In my view, the creation of incentives to develop and deploy new technologies, combined with incentives to undertake low-cost emission reductions in the near term, would represent real progress on the climate change issue. I believe that zero or negative emissions growth in the near term is not a realistic definition of progress for a growing economy like that of the United States.

Question 4. Has anyone looked at the cost of inaction—in other words, what the impact will be to the economy to not curb emissions? I'm thinking specifically of costs related to:

- health care due to dirtier air,
- insurance costs due to more intense storms,
- government emergency relief services,
- the costs of alternative sources of water in the west as the snowpack decreases,
- the costs of protecting homes, businesses and highways from rising sea levels,
- farm payments due to decreased agriculture output, and
- what the potential impact all of those increased costs will have on economic growth.

Answer. There is a large and growing literature on the impacts of climate change. I would refer you to the extensive studies published by the Intergovernmental Panel on Climate Change (IPCC), as well as those published by the U.S. EPA.

RESPONSE OF RICHARD D. MORGENSTERN TO QUESTION FROM SENATOR CORZINE

Question 1. A cap-and-trade policy is widely acknowledged as a mechanism that encourages industry to find the most cost-effective opportunities to meet a specific policy goal. It gives companies the flexibility to decide what types of actions and technologies work best for them. It is also widely acknowledged that improvements in other areas such as fuel efficiency would also have a significant impact on reducing greenhouse gas emissions, reducing air pollution, and increasing our energy independence. Wouldn't the reduction in greenhouse gas emissions be that much greater if we coupled a cap-and-trade policy with stricter CAFE standards?

Answer. It is true that short of very strict limits on emissions which, in turn, would lead to sharp increases in the price of gasoline and other carbon-based fuels, the emission reductions from automobiles under a cap and trade program of the type proposed by the NCEP are likely to be quite modest. Non-price measures clearly have a role to play in this sector. As currently designed, however, CAFE standards have some well-documented problems. Other program designs might be more effective in achieving mobile-source emission reductions with fewer unintended side effects.

RESPONSES OF ANNE E. SMITH TO QUESTIONS FROM SENATOR BINGAMAN

Question 1. Do you believe that climate change is linked to anthropogenic emissions?

Answer. I think there is enough evidence to warrant climate change risk management. My testimony outlined my thoughts on the key elements of such risk management.

Question 2. In your written testimony, you state that "a price on carbon in the near-term can be justified as a supplement to a meaningful R&D mission once that mission has clearly defined targets for success." and that "only government can provide the needed R&D investment."

Question 2a. What are your thoughts on how those long-term targets should be developed and, based on the targets, (i) what near-term carbon price would you suggest is reasonable and (ii) what level of funding would support a "meaningful" R&D program that would support these goals?

Answer. The nation needs to engage in a direct discussion of how to create an effective R&D program and what that program should strive to accomplish. The latter is what I mean by "targets for success." I, myself am just beginning to think about how one might put this together, but here are some initial thoughts that might help start a discussion. One important question is "What *would* the nation be willing to pay to achieve a zero-emissions energy system?" The current cost of a global zero-emission system is patently not acceptable. It also appears that lithe added cost of achieving a zero net GHG world were only a few percent of our current costs of energy, the nation might be willing to accept this cost to reduce climate change risk. Unfortunately, the latter situation is not a real choice at present, and no set of technology forecasts suggests that this will be possible even over the next 30 years. However, there might be some higher cost that we still would accept at some point in the future *if*, from that point on, it were to provide meaningful reductions in GHG emissions. The important question is whether this acceptable cost has any overlap with the costs that might be technologically achievable in the coming century with a concerted and focused R&D program.

The acceptable cost could be seen as a "stretch goal " for the R&D program. Setting such a goal is fundamentally a political process as it requires that uncertain risks of climate change be balanced against the more certain costs to our economy of using such future technologies on a scale that could actually stabilize atmospheric emissions. Economics might help inform a rational trade-off, but the stakes and associated uncertainties are so pronounced that the final choice for a cost goal depends on much broader social considerations.

Once the stretch goal for the R&D program has been articulated, then one can start to estimate reasonable levels of spending on near-term emissions reductions and the magnitude of the R&D task.

(i) A reasonable near-term carbon price would be the present value of the stretch goal for the future cost that we determine we are willing to accept for a zero-emissions economy. Calculating that present value is simple if one knows the future "acceptable" cost-per-ton that is the R&D goal, and the associated date of availability. Footnote 1 of my written testimony provided an illustrative example of such a calculation. It was *illustrative* because we currently lack both a national view of an "acceptable cost " for achieving zero net emissions, and an R&D program that offers a plan and target time period for deployment.

(ii) The level of funding for the R&D program would be determined by a process of identing the types of breakthroughs necessary to achieve the stretch goal. Once these R&D milestones have been identified, it will be more possible to discuss an appropriate scale and form for the R&D program, which in turn will identify the appropriate spending, and ramp-up rates for such spending.

Question 2b. How much do you expect this to cost the government?

Answer. See my reply to 2a(ii) above.

Question 2c. How much do you think the government would actually spend?

Answer. If an R&D program were to be developed that has a clearly articulated vision of what its targeted outcomes are, is founded on a political consensus that such outcomes would enable a national response to reduce emissions on a scale sufficient to meaningfully reduce risks of climate change, and with a coherent plan for how to make progress towards its defined goal, then it is likely that the government could agree on the spending necessary to fulfill the plan.

Question 2d. You said in your testimony that the difficult decisions are how much to spend now, and how to design programs to stimulate R&D that avoid mistakes of the past. Can you share your recommendations?

Answer. Designing a truly effective R&D program is clearly a major challenge yet it has not received even a modest amount of attention among climate policy analysts. My recommendation is that the community of environmental policy analysts immediately strive to shift their attention away from their traditional focus on devising efficient regulatory structures and focus it on the challenge of devising effective R&D programs. An intellectual cross-fertilization is needed between environmental economists and economists who have studied R&D processes. I am not saying that R&D should be solely a job for government. As I stated in my testimony, the objective should be to design a set of incentives that can shift private sector R&D in the direction of producing the needed advances for climate technology.

Question 3. You say that we need to develop "breakthrough" technologies, and that once they are developed we can make massive emissions cuts. You seem to acknowledge that this may still be "quite costly".

Question 3a. How many greenhouse gas emissions do you expect will be released between now and when these "breakthrough" technologies are developed and then deployed?

Answer. The quantity of GHG emissions that will be released over the next several decades will depend, at the margin, on the costliness of policies that are enacted around the world, and also on whether developing nations become engaged in any effort. However, under any scenario, we can expect that atmospheric concentrations will continue to rise until zero-emissions technologies start to be deployed on a global scale.

Question 3b. How certain are you that these "breakthrough" technologies will be created?

Answer. The likelihood of success depends on national and international efforts to identify the necessary component breakthroughs, and to create the programs that will help make them possible. Lack of such efforts reduces the likelihood that they will be created.

Question 3c. What if we fail to develop them?

Answer. If lower-cost zero-emissions technologies are not developed, then the world's economies will probably continue to emit GHGs at a rate that causes atmospheric concentrations to continue to grow.

Question 3d. Would you expect massive emission cuts by deploying the "breakthrough" technologies to lead to massive fuel switching from coal and other resources?

Answer. I have no idea.

Question 4. In your analysis of the NCEP proposal, how much money did you determine would be generated by the sale of allowances due to the auction and safety valve?

Answer. My testimony reported our analysis of the cap-and-trade portion of the Bingaman Amendment. We estimated a range of prices and emissions outcomes. Our estimates of revenues from the auction plus the safety valve sales (in 2005 constant dollars) are:

2010—$1 to 2 billion
2015—$2 to 3 billion
2020—$4 to 7 billion
2025—$5 to 12 billion
2030—$7 to 17 billion

The lower bound reflects just auction revenues, because our low case does not trigger any safety valve sales through 2030. Most of the difference between the lower bound and upper bound for 2020-2030 reflects revenues from safety valve sales.

Our analysis did not include the impact of the CAFE provisions. The CAFE standard would reduce the government revenue estimates, especially at the upper end of the range, while increasing the overall social costs of the program.

Question 5. According to NCEP recommendations, these revenues would then get redirected back into near term low carbon technology deployment programs (such as advanced nuclear, biomass, and coal with sequestration) as well as doubling basic energy R&D funds for the long term. In such a scheme, as the difficulty of the goals increased with the rise in the safety valve price, the funds going into technology innovation would also likewise increase. In your testimony, you indicate that the NCEP/Bingaman Amendment energy innovation funds are inadequate for the task at hand. How much more public money do you suggest be dedicated to energy research and development? How should these activities be funded?

Answer. My testimony related to the Bingaman Amendment as written, and did not relate to any provisions or recommendations in the NCEP proposal that were not reflected in the Bingaman Amendment. I did wish to suggest that current R&D spending was inadequate for the task at hand; rather, I argued that the nation is lacking a clearly targeted and carefully planned R&D program to develop much lower cost options for a zero-emissions economy, and that the Bingaman Amendment would not help fill this gap. I argued that subsidies increased the cost that we will spend on near-term technologies to a level above that implied by the safety valve, which is inappropriate if the safety valve represents the maximum that we should be spending today on near-term reductions. I also argued that spending on subsidies did not constitute spending on R&D.

See my reply to question 2a(ii) regarding my thoughts on how to determine how much public money should be dedicated to energy R&D. Once appropriate funding levels have been determined, I feel that it is up to the Congress to determine how to raise the funds. I stated in my testimony that I do not think that the funds should come solely from a carbon tax allowance auction, or safety valve sales. Such revenue sources might generate either too little revenue or too much revenue to serve a well-targeted and well planned R&D program, and so they should not be formally linked to each other. Additionally, I do not recommend that a carbon tax rate or safety valve price be chosen based on R&D spending needs; the appropriate level should be based on considerations such as I outlined in my reply to question 2a(i).

Question 6. What are the advantages and disadvantages of using intensity-based emission targets?

Answer. I see no particular advantages or disadvantages of basing a cap-and-trade program on intensity-based emission targets. The only merit of the concept is that it has enabled the nation to recognize that a "cap" might allow for emissions to increase from where they are today, yet still impose a real cost on the economy, and require concerted effort to achieve. However, as implemented in the NCEP proposal and the Bingaman Amendment, it is still a cap, with attending concerns about cost uncertainty and variability. More importantly, the cap in these two proposals, whether intensity-based or not, is rendered almost completely irrelevant by the safety valve provision, which converts the "cap" into an effective tax.

Question 7. What are your views on setting up a trust fund with the proceeds from a cap and trade program and using the revenue to fund investment in low emission energy technologies?

Answer. See the second paragraph of my reply to question 5.

Question 8. As you know, we are operating under huge budget deficits and, therefore, massive appropriations for R&D are unlikely. Given this context, if the Bingaman proposal was modified to fund "Long-run, high-risk R&D to produce radically new GHG-free energy sources," rather than subsidies for existing technologies, could you support it?

Answer. My replies under questions 2 and 5 above sum up my view of an appropriate set of actions and policies to mitigate climate change risk. That approach is fundamentally different from the Bingaman proposal, and it would not be achieved by merely changing the earmarking of funds for subsidies to earmarking of funds for R&D. First, and foremost, specific national goals for an R&D program must be articulated and that important gap would not be filled by simply altering what the revenues are earmarked to be used for. Spending on R&D without first determining what would constitute "success " and ident0ing how to maximize chances of success would probably just be a waste of money.

My testimony also emphasized that a carbon tax is a simpler and more transparent way of achieving a goal of placing a near-term price on GHG emissions. I have also concluded that using CAFE standards, which currently are in the Bingaman proposal, is less cost-effective than using a price signal to drivers of current automobile technology combined with a program for the long-run development of a future, zero-emitting form of personal transportation.

Question 9. Under what conditions could you support a carbon tax?

Answer. See my reply to question 2a(i).

Question 10. You state that "the 'safety valve' in the NCEP program and Senator Bingaman's amendment is designed to provide assurance that the price of emission allowances will not reach economically unsustainable levels. But that policy design causes the prices to be set at a level far too low to provide an adequate incentive for private investors to develop radically new technologies." Yet earlier you note that only a low price would be justified. What price does your analysis suggest would be appropriate to encourage private investors to develop radically new technologies (a) on their own, and (b) in conjunction with an appropriate R&D program?

Answer. I conclude that no price signal created by government legislation or regulation can provide the incentives necessary for private investors to develop radically new technologies. This is because of a dynamic inconsistency of incentives that is the subject of my recent paper with Dr. David Montgomery, and which is described in my written testimony on pp. 17-19. Price signals are useful for motivating the private sector to deploy technologies that currently exist but which would be more costly than higher-emitting technologies *but for* a carbon price that we are willing to impose and pay for now. Such price signals might also motivate private entities to make some *evolutionary* improvements on existing technologies that could quickly bring them into the cost-effective range defined by a credible and sustainable near-term carbon price. My thoughts on what that near-term carbon price level might be are described in my response to question 2a(i) above. Motivation to develop *revolutionary* technologies, requiring the coordination of a set of many separate scientific breakthroughs, must come from other forms of policy than a carbon price signal. Their eventual deployment can be motivated by a carbon price signal once the technology has reached the deployment stage, which occurs after the R&D stage.

RESPONSES OF ANNE E. SMITH TO QUESTIONS FROM SENATOR AKAKA

Question 1. From what you and Dr. Morgenstern state in your testimonies, there is virtually no way that the U.S. can do anything that will reverse global warming. Even reductions to zero carbon emissions right now will hardly stabilize temperature.

Answer. Even if the U.S. were to reduce its emissions to zero right now, emissions in developing countries would continue unabated and so atmospheric concentrations would continue to increase too. Atmospheric stabilization can only be achieved if the entire globe moves to zero carbon emissions. This is why it is so important for a US policy response to directly address the need for reducing developing country emissions and not just focus on reducing US contributions to emissions.

Question 2. Your testimony emphasizes the importance of investing in R&D for technology, particularly "radically different" technologies for limiting carbon emissions. If the nation were to embark on one of the three options in your testimony (cap & trade, cost-based, or carbon tax), how do you see economic growth distributed in the technology community or the U.S. in general? Which types of business would be the winners—where would you expect to see economic investment, jobs, and growth? Would it be large coal technologies, for example, or small electronics firms or carbon material firms?

Answer. The "winners" will depend on the focus of the R&D program that I have argued should be developed as a first step. I do not know what that focus would be. However, I am confident that a sound program will require a diversified approach and that will imply opportunities to contribute to the program will be available in many sectors of the economy.

RESPONSES OF ANNE E. SMITH TO QUESTIONS FROM SENATOR FEINSTEIN

Question 1. Under the National Commission on Energy Policy's proposal, what happens when a covered entity uses the safety valve rather than lowering emissions? What is done to ensure that emissions are actually reduced?

Answer. When a covered entity "uses" the safety valve, it pays money to the government equal to the safety valve price in that year times the amount by which its actual emissions exceed its holdings of allowances (both allocated allowances and those purchased after the allocation). The safety valve therefore does not require that emissions are actually reduced; it does however ensure that covered entities have a real financial incentive to achieve all the emissions reductions that they can find at a cost per ton reduced that is cheaper than the safety valve price.

Question 2. Under the Commission's proposal, a company could pay the $7/ton fee instead of reducing the greenhouse gases. So, in the end, is there really a firm cap on emissions?

Answer. No, there is not a firm cap on emissions.

Question 3. What policy solutions do you recommend to correct for this so we can still make environmental progress?

Answer. My written and oral testimonies have consistently recommended that the nation develop and implement an effective, long-term R&D program to enable us to achieve an affordable, zero net emissions energy system within the century—hopefully starting within the next 30 years. For near-term actions, I have recommended that we focus (1) on achieving transfer of current state-of-the-art technologies to developing countries that still investment in less efficient technologies even as they grow, and (2) on creating a price signal on domestic emissions that will incentivize the reductions that are cheaper now than the present value of making those reductions later with more advance and cheaper technologies.

Question 4. Has anyone looked at the cost of inaction—in other words, what the impact will be to the economy to not curb emissions? I'm thinking specifically of costs related to:

- health care due to dirtier air,

- insurance costs due to more intense storms,
- government emergency relief services,
- the costs of alternative sources of water in the west as the snowpack decreases,
- the costs of protecting homes, businesses and highways from rising sea levels,
- farm payments due to decreased agriculture output,
- and what the potential impact all of those increased costs will have on economic growth.

Answer. There is no firm scientific basis currently linking the above consequences to increasing atmospheric concentrations of greenhouse gases. There is a general consensus among climate modelers that it is currently impossible to calculate the effects of atmospheric concentrations at a sufficient level of regional detail to predict even the direction of change in these potential consequences. However, various analysts have attempted to make "what-if" calculations of benefits that assume a particular relationship. Even so, their general conclusions have been that very high cost near-term emissions reductions (e.g., costs of the level that economists project would occur under a hard cap such as McCain-Lieberman's or the Kyoto Protocol) are not justifiable. This is largely because these costly near-term actions will have no meaningful impact to reduce the risks of any of the possible outcomes you have listed above.

Risks to health of air pollutants are already managed under the Clean Air Act, and there are far less costly methods for reducing these pollutants than a carbon emissions cap.

Question 5. Your testimony includes a number of comments regarding the allocation of allowances under a greenhouse gas emissions cap-and-trade programs. This is a critical issue in putting together such legislation. What is your recommendation regarding how the allowances should be allocated?

Answer. Allocation schemes mainly alter the burden sharing under a cap-and-trade program, and so the decision on allocation of allowances is an inherently political process driven by multiple social objectives. Analysis methods may be useful to help politicians and affected parties understand the sharing of the burden associated with different allocation schemes, but they cannot provide enough certainty and specificity to positively identify appropriate or "fair" allocations even if the normative goals were to be specified. It is particularly important to recognize that there is no allocation scheme under a cap-and-trade program that can make everyone whole: even the most cost-effective program will have a net cost, and someone (some groups) will ultimately have to bear that cost burden.

As noted in my testimony, some attributes of an allocation scheme can actually exacerbate a cap program's cost, and politicians should avoid those situations when attempting to devise a politically acceptable set of allocations. These include (a) failing to recognize the need to replace government revenues that may decline due to the economic impact of the cap, and (b) allocation rules that update what a company will receive in future years on the basis of their future business outcomes.

RESPONSE OF ANNE E. SMITH TO QUESTION FROM SENATOR CORZINE

Question 1. Are you convinced that global climate change is linked to anthropogenic emissions?

Answer. I think there is enough evidence to warrant climate change risk management. My testimony outlined my thoughts on the key elements of such risk management.

RESPONSES OF JASON S. GRUMET TO QUESTIONS FROM SENATOR BINGAMAN

Question 1. Emission trading programs have been highly successful in phasing out leaded gasoline and CFCs, and most notably in reducing emissions of SO_2 and NO_X through the Acid Rain trading program. Is emission trading a good policy instrument for addressing climate change? Why or why not?

Answer. Emission trading has proved to be a highly effective policy instrument for addressing a variety of environmental problems. Moreover, this approach is likely to be especially well-suited to reducing emissions of the chief greenhouse gases implicated in human-induced climate change.

The generic advantage of an emission trading approach is that it can achieve maximum environmental benefit at minimum cost by allowing individual sources to exploit the lowest cost emission-reduction opportunities available to them. This means that sources in a position to cheaply cut emissions can implement more than their share of reductions and sell excess permits or allowances to other sources that face higher costs. As such, a trading program is far more flexible and cheaper than a command-and-control approach, where strict control requirements typically apply to each individual source. The proposal put forward by the National Commission on Energy Policy goes even further to ensure that costs are known—and "capped"—in advance by including a safety-valve mechanism that allows sources to buy an unlimited quantity of additional permits from the government at a pre-determined price.

Emission trading programs work best where the following conditions obtain:

- The underlying environmental problem occurs over a large area, rather than being highly localized.
- A large number of sources are responsible for the problem.
- The cost of reducing emissions varies from source to source.
- Emissions can be consistently and accurately measured.

All of these criteria are met in the case of climate change. First, the underlying problem occurs over the largest possible area—the entire planet. From the standpoint of warming impacts there is no local component to greenhouse gas emissions—their effects on the atmosphere are the same wherever they occur. Second, emissions of greenhouse gases from different sources vary widely, as do the opportunities and costs for reducing those emissions. Finally, it is not difficult to accurately track and report the vast majority of emissions of carbon dioxide, the most important anthropogenic pollutant implicated in global warming. Carbon dioxide emissions accounted for nearly 85 percent of the overall U.S. greenhouse gas emissions inventory in 2003; of these emissions, nearly all (98 percent) were energy related—that is, they resulted from the combustion of fossil fuels like coal, oil, and natural gas. Unlike other energy-related pollutant emissions, which can vary widely depending on combustion conditions, the type of pollution control equipment in place (if any), and a host of other parameters, carbon dioxide emissions are a straightforward function of the carbon content inherent in the fuel being consumed and can be calculated simply and precisely long before combustion actually occurs. This feature means that the requirement to hold emissions permits (otherwise known as "point-of-regulation") can occur anywhere along the fuel production, distribution, and consumption supply chain. It also means that the great majority of regulated entities do not need to install new emissions monitoring equipment, they need simply keep track of the type and amount of fuel for which they are responsible within the emission trading program.[1]

Question 2. You seem to agree that the most important long-term feature of any climate policy is the impact it will have on investment in R&D and the development of new, carbon-free technologies in both the private and public sectors. What do you believe are the best policies for pursuing needed R&D? Should these R&D initiatives be primarily tax-payer funded, government R&D programs, or should we pursue policies to provide incentives for private sector R&D?

Answer. As I stressed in my testimony, the National Commission on Energy Policy strongly believes that a combination of public and private sector R&D is crucial to develop the new technologies that will be needed to effectively reduce not just U.S., but global, greenhouse gas emissions over the coming decades. We further believe that the best and most effective means for stimulating technology investment is to combine a market signal for reducing emissions with increased public funding and performance-oriented government incentives aimed at developing and commercializing low-and non-carbon energy alternatives. In our proposal, a cost-capped emission trading program provides the crucial market signal by creating real economic incentives for the private sector to avoid emissions and invest in climate-friendly technologies. This market signal is complemented by increased funding for both government and private-sector efforts to develop longer-term technologies, such as carbon sequestration, large-scale renewables, or advanced nuclear, that would otherwise remain uneconomic in the face of the relatively modest carbon price implicit in our emissions trading proposal.

As to the question of whether public funding should be primarily directed toward government R&D versus private-sector R&D, the Commission believes that both sectors have important assets and expertise and that both must play a significant role in advancing new technologies. The final chapter of our report contains a detailed discussion of the specific stages of energy-technology innovation and of the different and complementary roles of the public and private sectors in moving new tech-

[1] Emissions of other greenhouse gases, notably methane, nitrous oxide, HFCs, PFCs, and SF6, can be more difficult to track and document, but these emissions account for a much smaller share of the overall inventory. In the case of methane and nitrous oxide, the next most important greenhouse gases in the United States, methodologies for estimating emissions from a variety of sources have been developed and refined over several years and can be used where direct measurement of emissions may not be feasible.

nologies through these stages, which include applied research, development, demonstration, early deployment, and widespread deployment. Typically, government institutions play a larger role in the early stages of that progression (fundamental and applied research), while private-sector actors play an increasingly dominant role in the latter stages (that is, from development and demonstration through deployment). The following paragraph from our report captures our basic view of how best to leverage a combination of private and public sector R&D efforts:

> "Complementarity of public-sector investments and incentives with the private sector's efforts means that the publicly supported efforts should be focused precisely on those ingredients of a societally optimal energy research, development, demonstration, and early deployment (ERD^3) portfolio that industry would not be supporting on its own—avoiding the error of paying industry with public funds to do what it would otherwise be doing with its own money. Complementarity also means exploiting the complementary technology-innovation capacities of industry and publicly funded national laboratories and academic research centers. In many cases this should entail actual partnerships, in which industry's role will naturally increase as the innovation process in any particular case proceeds . . . specifically, as a technology moves from applied research through development, demonstration, and early deployment, the insights about commercial products and the marketplace that are industry's fort become increasingly indispensable to success." (National Commission on Energy Policy, *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges*, December 2004, p. 100)

Question 3. Roughly how large an R&D investment do you believe is needed at this time, given that radically new technologies will be required in the future to address climate change? Are current energy R&D funding levels adequate, or do you think additional resources are required?

Answer. Among the Commission's most important findings was the finding that current energy-related R&D investment by *both* the public and private sectors falls far short of what is needed to successfully address climate change and meet the other critical energy challenges we face in the next century. In fact, energy is by far the *least* R&D intensive high-technology sector in the U.S. economy at present. Even as total energy sales in the United States rose from $500 billion per year in 1990 to about $700 billion per year today, private-sector investment in energy R&D investment fell by roughly half, from about $4 billion per year in 1990 to about $2 billion per year at present. Federal investment in energy R&D, meanwhile, has averaged well under $3 billion per year since the late 1980s—it rebounded slightly in the early 2000s after reaching a low of less than $2 billion per year in 1998, but remains (in constant 2000 dollars) far below the nearly $6.4 billion level of investment reached in the late 1970s. Moreover, the portion of overall federal appropriations devoted to *applied* energy-technology RD&D in the FY2004 budget came to only about $1.8 billion (compared to $6.08 billion in FY1978). Overall, combined private-sector and federal funding for energy R&D amounts to less than 1 percent of energy sales, a level of investment that is far below the average for other high-technology industries.

Deciding how much energy R&D investment is "enough" is, of course, difficult, since the answer depends not only on the level of expenditure being considered, but on the difficulty of the challenges being addressed and the effectiveness of the R&D efforts being mounted to address those challenges. Nevertheless, as we point out in our report, every study in recent years that has attempted to look comprehensively at this question has concluded that current efforts in both the public and private sectors are not commensurate in scope, scale or direction with the challenges, the opportunities, and the stakes at hand. To remedy this shortfall, the Commission recommended roughly doubling annual direct federal expenditures on energy research, development, and demonstration. Specifically, our recommendations included:

- Revising the energy-relevant provisions of the tax code to substantially increase private-sector incentives to invest in energy research, development, demonstration, and early deployment (ERD^3).
- Doubling annual direct federal expenditures on energy research, development, and demonstration over the period from 2005-2010 (corrected for inflation)—with increases emphasizing public-private partnerships, international cooperation, and energy technologies offering high potential leverage against multiple challenges.
- Creating a serious and systematic "early deployment" component to complement the increased research, development, and demonstration activity with effective, accountable, and performance-oriented approaches to accelerating the attain-

ment of market competitiveness by the most promising technologies that successfully pass the demonstration phase.
- Expanding by at least three-fold, within the above-recommended increases in federal ERD[3] efforts, the government's activities promoting and participating in international cooperation in this domain.
- Strengthening the organization and management of the federal governments ERD[3] activities through continuation and expansion of the efforts already underway in the Department of Energy (DOE) to improve communication, coordination, portfolio analysis, and peer review in DOE's ERD[3] programs and pursuing increased coherence and self-restraint in the Congressional "earmarking" process for ERD[3] appropriations.

A further point, which I also stressed in my testimony, is that the Commission felt it very important to ensure that additional public spending on energy R&D would not add to the current burden on the U.S. Treasury or compound our mounting national debt. Accordingly, we recommend that any new public investments in energy R&D be funded through the new revenues raised by auctioning a small portion (maximum of 10 percent) of the emissions permits allocated under our recommended greenhouse gas trading program and through sales of additional permits under that program via the safety valve mechanism. Further details and discussion concerning the Commission's energy-technology incentive and R&D recommendations can be found in our full report.

Question 4. What are the advantages and disadvantages of using intensity-based emission targets?

Answer. The chief advantage of an intensity-based approach is that it creates an environmental target that is flexible and responsive to economic conditions. As such, the very formulation of the target makes explicit the notion that our goal in the first decade of program implementation is only to slow, not stop, current growth in national greenhouse gas emissions and to improve the efficiency of the American economy by reducing its energy intensity: This is a goal that is broadly supported by both political parties and by the American public (it is worth noting that the Bush Administration's voluntary greenhouse gas reduction target is also expressed in intensity terms). By contrast, setting a fixed emissions target tends to arouse concerns that a policy to limit greenhouse gas emissions will necessarily limit future economic growth. The choice of an intensity-based target, together with a safety-valve mechanism to limit the economic cost of implementing overall reductions, results in a policy that, according to an independent analysis by the federal Energy Information Administration, would have no material effect on "the overall growth rate of the economy between 2003 and 2025, in terms of both real GDP and potential GDP."[2]

Another key advantage of an intensity-based approach is that it is more amenable to developing country participation. Developing countries are especially sensitive to the concern that limiting greenhouse gas emissions will limit growth. By supporting the use of intensity metrics in greenhouse gas management regimes that naturally accommodate emissions growth, the United States would be designing a framework that is more likely to encourage developing country participation.

Finally, a related advantage of an intensity-based approach is where it sets the bar for future policy debate. A fixed target is inflexible by design, politically contentious to iterate, and prone to over-determined conclusions about the success or failure of the policies used to achieve it. In contrast, negotiations based on intensity goals are about the rate of decline and offer greater opportunities for fine-tuning and adjustment. As such, this approach may prove more robust and resilient than the alternative approach of setting absolute goals based on historic emissions levels.

However, it should be noted that, the very attributes that make an intensity approach well suited for the initial decades a carbon management program may eventually need to be reconsidered if a global scientific and political consensus forms around a desired absolute emissions target. As the global effort to address climate change matures, it may eventually become reasonable to place less emphasis on providing economic certainty (through mechanisms such as the safety valve and the intensity target) while placing more emphasis on achieving and maintaining a fixed environmental outcome. For just this reason and because it is inherently impossible to prejudge developments that might affect policy deliberations decades into the future, the Commission has not attempted to articulate detailed recommendations for how its proposed policy would evolve beyond the 2020-2025 timeframe. In the mean-

[2] As noted in my testimony, the LIA analysis specifically found that the cumulative effect of the Commission's recommended greenhouse gas emission trading program would be to reduce overall predicted GDP growth between 2005 and 2025 from 80.8 percent to 80.6 percent, or a difference of 0.2 percent.

time, however, we believe that our proposed approach achieves an appropriate balancing of the need for economic versus environmental certainty and that the advantages of setting emissions targets on an intensity basis outweigh the disadvantages of using this approach.

Question 5. What are your views on setting up a trust fund with the proceeds from a cap and trade program and using the revenue to fund investment in low emission energy technologies?

Answer. As noted above and in my earlier testimony, the Commission strongly recommends that additional public investment in low-and non-carbon energy technologies should be funded by the auction of a portion of permits or allowances under its proposed emission trading program, together with revenues generated by the sale of additional permits or allowances through the safety valve mechanism. Because significant global reductions in greenhouse gases will eventually require the development and large-scale deployment of new technologies, these investments are absolutely critical if we are to achieve long-term success in dealing with climate change while simultaneously ensuring continued access to reliable and affordable energy supplies. The Commission considered the relative merits of "on-budget" and "off-budget" funding strategies. In light of Congress' historic reluctance to support "off-budget" funding mechanisms and the challenges inherent in creating a new institution, the Commission focused its recommendations on opportunities to build upon recent successful efforts to improve the effectiveness of existing government technology programs. While recognizing that Congress alone is responsible for appropriations, the Commission believes that the practice of non-competitive earmarks has in some cases undermined the effectiveness of public funds spent on energy technology innovation and believes that greater efforts are needed to ensure that earmarks are consistent with the strategic objectives of the programs affected.

RESPONSES OF JASON S. GRUMET TO QUESTIONS FROM SENATOR AKAKA

Question 1. My question has to do with sequestration of carbon. Did your Commission look at various ways to enhance sequestration of carbon—that is, taking carbon out of the earth's biosphere by a number of means including storing it in oceans and increasing plant biomass? Did the Commission see this as a viable means to reduce carbon? How did the Commission see it as participating in the overall market?

Answer. The Commission believes that geologic sequestration is a promising strategy for reducing the climate impacts associated with future use of traditional energy resources, most notably coal. In particular, we looked at geologic carbon sequestration in combination with the development and deployment of advanced integrated gasification and combined cycle (IGCC) coal-fired electricity production. Potential repositories for geologic carbon sequestration include depleted oil and gas fields, unmineable deep coal seams, or deep saline formations. In general, we are optimistic about the potential role for geologic carbon sequestration as part of an array of strategies for mitigating climate change risks in the future. This optimism is based on the size of potential geologic repositories in the United States, which, according to current estimates, could theoretically hold hundreds of years worth of current U.S. emissions and on the fact that all aspects of the technology required for carbon capture and sequestration are developed and in use today, primarily to support the use of carbon dioxide injection for oil recovery. Further investment is required, however, to reduce costs and to demonstrate and deploy these technologies on the scale needed for meaningful capture and sequestration in the context of a larger greenhouse gas management strategy. The Commission's recommendations therefore include $3 billion in public support over ten years for the commercial-scale demonstration of geologic carbon storage at a variety of sites around the country, both in conjunction with coal IGCC plants and as stand-alone sites.

While our analysis focuses primarily upon geologic sequestration, the Commission recognizes the important role that biological sequestration must also play in long-term carbon management strategies and believes that there are a variety of opportunities for agriculture and forestry industries to profit as the sellers of reduction credits under a market-based emissions trading program. One biological sequestration strategy that the Commission devoted considerable attention to is the opportunity to accelerate commercial scale production of ethanol from cellulosic biomass. We believe that this technology is particularly attractive due to the combined benefits cellulosic ethanol offers for climate change mitigation and improved oil security. The Commission did not look closely at deep-ocean sequestration strategies.

Question 2. Clearly the participation of developing countries in a global carbon reduction effort is necessary to make a difference on global greenhouse gases. How does the Commission see that link or challenge working—between developed nations that have adopted carbon controls, and either leading or pushing countries such as China and India to adopt similar emissions controls? What does the Commission see as the best way to ensure those changes?

Answer. The Commission wholeheartedly agrees that the problem of climate change requires a global response and cannot be meaningfully addressed on a long-term basis without full participation by all major emitting nations, including developing nations such as China, India, and Brazil. We believe the best way to elicit an equitable and effective global response is for the United States to return to a position of international leadership on this issue by taking an initial step domestically, while designing that initial step so that it explicitly links future U.S. action to limit greenhouse gas emissions to comparable efforts by other developed and developing nations to achieve their own emissions reductions. Thus, our proposal for a mandatory, economy-wide U.S. greenhouse gas emissions trading program is intentionally phased and carefully designed to protect our economy from competitive disadvantage if other nations fail to limit their emissions. It also contains an important provision for periodic five-year reviews of the U.S. program which would enable Congress to assess progress by other countries as part of a determination of how domestic efforts should evolve. Specifically, the Commission recommends that if:

> "other countries with significant emissions and/or trade with the United States do not take comparable action to limit emissions by 2015, five years from the commencement of the U.S. program, further increases in the safety valve price should be immediately suspended. Depending on international progress, the United States could also opt not to introduce a more ambitious target rate of emissions intensity improvement in 2020 and make other adjustments to its domestic program; conversely it could decide to move forward more aggressively in the second decade of program implementation than the Commission is proposing." (National Commission on Energy Policy, *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges*, December 2004, p. 25)

By explicitly linking future U.S. actions to international progress, the Commission hopes to create a "push" for developing country involvement in climate mitigation efforts. That push should be combined with positive incentives aimed at "leading" other countries toward participation. Accordingly, we recommend that the United States continue and expand its current bilateral negotiations with nations such as China, India, and Brazil while also providing incentives to promote technology transfer and to encourage U.S. companies and organizations to form international partnerships for implementing clean energy projects in developing nations.

Finally, it is important to recognize that a number of countries are already taking steps to limit greenhouse gas emissions. This includes not only our major trading partners in the developed world, many of whom (including the European Union, Japan, and Canada) have adopted the Kyoto Protocol and begun efforts to implement their obligations under Kyoto, but also several key developing nations that have begun reducing their emissions below forecast levels as they pursue enhanced energy security, energy efficiency, conventional pollution control, and market reform. These developments are encouraging and provide grounds for optimism U.S. efforts to address our own contribution to the climate problem would prompt an international response more likely to exceed our expectations than to disappoint them.

RESPONSES OF JASON S. GRUMET TO QUESTIONS FROM SENATOR FEINSTEIN

Question 1. Under the National Commission on Energy Policy's proposal, what happens when a covered entity uses the safety valve rather than lowering emissions? What is done to ensure that emissions are actually reduced?

Answer. Differing opinions about the pace of technological progress make it impossible to confidently predict both the costs and benefits of mandatory greenhouse gas reduction efforts. Through inclusion of a "safety-valve" mechanism to cap program costs, the Commission is expressing a preference for cost-certainty over emissions certainty in the initial stages of a carbon management regime. Ultimately, addressing the threat of climate change will require global agreement about an ecologically sustainable emission limit and an equitable sharing of reduction burdens. Achieving the long-term environmental objective will likely require that fixed emission limits eventually replace cost-based policies. However, the Commission strongly believes that reducing uncertainty about near-term economic impacts is crucial to creating a consensus for timely action.

A cap and trade program with a safety valve will function exactly like a traditional cap and trade regime until and unless technology fails to progress as desired.

Under a traditional cap approach, slower than desired technological progress results in higher than anticipated program costs. Through inclusion of the safety-valve compliance mechanism, a failure of technology to progress as the desired rate will cause firms to purchase additional emission permits from the government at a set price leading to lower than anticipated emission benefits. The Commission and the Energy Information Administration have each analyzed the projected impacts of the Commission's climate program under a range of technology assumptions. Both conclude that under relatively optimistic technology assumptions, the safety-valve will not be triggered and full program benefits will be achieved. Conversely, under more pessimistic technology assumptions, firms will take advantage of the safety valve compliance option resulting in roughly half of the emission benefits. Advocates for mandatory climate action generally tend toward technology optimism arguing that main economic models fail to capture a range of cost-effective compliance options. If correct, the safety-valve will simply have served to allay the anxieties and speeded adoption of a meaningful reduction program. If incorrect, the safety-valve will serve its intended purpose of achieving all available emissions reductions *up to*, but not *beyond*, the point where overall costs to the economy are deemed acceptable by policymakers.

The Commission has proposed a price—starting at $7 per metric ton of carbon-dioxide-equivalent in 2010 and escalating in nominal terms by 5 percent per year thereafter—that is high enough, in our judgment, to achieve substantial emissions reductions and generate a meaningful market signal for encouraging investment in low-and non-carbon alternatives, but not so high as to materially impact the U.S. economy or undermine the competitiveness of U.S. firms in international markets.

Question 2. Under the Commission's proposal, a company could pay the $7/ton fee instead of reducing the greenhouse gases. So, in the end, is there really a firm cap on emissions?

Answer. There is no firm cap on emissions in the Commission proposal.

There is no debate over the fact that a carbon program with a $7 per ton CO_2 cost cap sends a weaker market signal than a program in which limits must be achieved regardless of economic impact. However, it is worth noting that most greenhouse gas cap-and-trade proposals to date have included a variety of so-called "flexibility mechanisms" that would, in practice, also allow domestic emissions to rise above the stated cap. Since the costs associated with achieving a fixed level of emissions reduction cannot be known in advance, cost arguments are impossible to adjudicate to the satisfaction of all stakeholders and will likely continue to stymie efforts to reach political consensus. Hence our Commission believes that the more meaningful comparison may be between the timely adoption of a cost-capped mandatory program and the continuation of business as usual in which domestic carbon emissions can be vented into the atmosphere at no cost. From ecological, economic and political perspectives the Commission believes that speeding the adoption of a robust policy architecture to address the long-term challenge of climate change is more important than achieving a precise level of near-term emission reductions.

Question 3. What policy solutions do you recommend to correct for this so we can still make environmental progress?

Answer. We regard the safety valve feature as a key virtue of our proposal and do not believe it requires "correction." Proposals, which may set strict caps and look more aggressive on paper, won't result in progress if they never succeed in garnering the political support needed to implement them. Congress has repeatedly gone on record in support of action on climate only if such action does not damage the U.S. economy or undermine U.S. competitiveness. We believe our proposal meets that test, while still achieving substantial reductions below the emissions trajectory projected absent policy intervention. Specifically, modeling analyses conducted using conservative assumptions about technology innovation indicate that our proposal will produce 540 million metric tons of carbon-dioxide-equivalent greenhouse gas reductions in 2020, a 6 percent reduction below business-as-usual projections. Under more optimistic technology assumptions, estimated reductions in 2020 could roughly double to approximately 1 billion metric tons.

While our proposal certainly achieves progress in slowing emissions growth over the first decade of program implementation, its more important contribution over the long run is likely to reside in the market signal it creates for avoiding future emissions. Only when greenhouse gas reductions have a concrete value will the tremendous ingenuity and investment potential of the American economy be brought to bear in developing and deploying the new technologies needed to achieve more substantial emissions reductions in the future—not only in the United States, but worldwide.

The initial market signal created by the Commission's proposal—at $7 per metric ton of carbon dioxide—is admittedly modest. As I noted in my testimony, we selected this figure because our analysis of the available literature suggested it roughly corresponds to the mid-point of current estimates of the expected harm that can be attributed, based on present scientific understanding, to a ton of greenhouse gas emissions. Perhaps more importantly, at $7 per ton the safety valve price was sufficiently low as to minimize the immediate burden on consumers and business and avoid forcing the premature retirement of long-lived capital assets (such as power plants) that were constructed before climate concerns figured in the investment decisions of most energy companies, while still creating a meaningful market signal for avoiding future emissions. Certainly a stronger initial signal would produce a stronger initial response, but it would also be more costly to the economy. Finally, it is important to emphasize that the market signal under the Commission's proposal grows steadily stronger over time as the nominal safety valve price increases by 5 percent per year. This gradual but measurable progression in the stringency of the program gives businesses the planning certainty they need to make wise long-run investments that will minimize the costs of achieving greenhouse gas emissions reductions over time.

In sum, as I noted in the previous response, the decision about where to set the safety valve price is ultimately a political one. Ultimately it is probably less important what specific price is chosen than that we get started. The Commission believes its proposal—by removing cost uncertainty as a basis for inaction—offers the best chance we have right now to do just that.

Question 4. Has anyone looked at the cost of inaction—in other words, what the impact will be to the economy to not curb emissions? I'm thinking specifically of costs related to:

- health care due to dirtier air,
- insurance costs due to more intense storms,
- government emergency relief services,
- the costs of alternative sources of water in the west as the snowpack decreases,
- the costs of protecting homes, businesses and highways from rising sea levels,
- farm payments due to decreased agriculture output,
- and what the potential impact all of those increased costs will have on economic growth.

Answer. In the early stages of its deliberations, the Commission reviewed the available literature on potential costs associated with future climate change, including costs associated with many of the categories of possible impact listed in the question. Some of this material is available in a separate compendium of research that the Commission compiled as part of its final report and that we would be happy to make available to the Committee. The short answer to the question is that inaction will almost certainly impose costs on our economy and there is good reason to believe that these costs could be quite large. The difficulty, of course, is in quantifying these costs given the numerous uncertainties that are involved; the complexity of various feedback mechanisms, not only within the climate system but in the natural and human systems that are intimately affected by climate; and the inherent difficulty of assigning a specific value to things like species diversity and ecosystem preservation. Not surprisingly, analyses that have attempted to derive cost estimates for the likely impacts of climate change have therefore produced a wide range of results.

In fact, as is often the case with important environmental issues, it is even harder to agree on the cost of inaction than it is to agree on the cost of taking steps to mitigate the problem. For this reason, Commission members agreed that it would be unproductive to become bogged down in either side of the cost debate. A much simpler conclusion: that the overwhelming weight of scientific evidence points to the risk, if not the certainty, of potentially significant adverse harms and that cautious steps are warranted at this time to begin reducing that risk, provided an adequate basis for consensus within our own very diverse group and should, in our view, provide an adequate basis for action by Congress. In fact, we believe a modest and gradual approach such as we have proposed, because it is inherently flexible and can be fine-tuned as better information becomes available, is precisely the best response in a situation where uncertainties abound on both sides of the impact versus mitigation cost-debate. The key is to start now, because by doing so we effectively buy time to make adjustments if climate change and the consequences it unleashes turn out to be worse than expected. By contrast, each additional year of political stalemate and inaction simply limits our options and increases the risk that we'll eventually realize we should have done more, but realize it only when it is already too late.

RESPONSES OF JASON S. GRUMET TO QUESTIONS FROM SENATOR SALAZAR

Question 1. Mr. Grumet, thank you for your participation today and for your work on the National Commission on Energy Policy. The NCEP proposal would have a very modest effect on the economy. Furthermore, your climate change proposal takes great pains to ensure no one source of energy is put in an unfavorable position compared to others.

Now, this is very important to me, because as you know coal is a large part of the Colorado economy, and in fact it is a large part of America's energy future.

Can you explain how the NCEP climate change proposal will prevent coal from being adversely affected?

Answer. Commission members recognize the extremely important role that coal plays in the nation's and the world's energy mix and took care to develop policy recommendations that offer, in our view, the best odds of ensuring a continued and significant role for coal in the future. Our approach is two-fold. On the one hand, the near-term policy we have proposed for slowing growth in U.S. greenhouse emissions is designed—both in terms of the target it sets, the cost certainty it provides, and the very gradual way in which it progresses—to minimize adverse impacts on coal and give the industry an opportunity to adjust successfully to emerging climate constraints. As a second, critical policy complement to this program, our recommendations provide for substantial public investment in helping the coal industry to develop and deploy a next generation of technologies that are compatible with the need to limit greenhouse gas emissions and address a number of other coal-related environmental concerns.

With respect to the Commission's climate change proposal, we looked specifically at the impacts of our greenhouse gas trading program on the coal industry. As one would expect, the effects of the proposal on coal use and coal prices would be somewhat more significant than the effects on other, less carbon-intensive fossil fuels like natural gas and oil. Nevertheless, under our proposal projected coal consumption in 2020 is reduced by only 9 percent relative to the business-as-usual forecast and overall coal use still rises by 16 percent compared to current (2004) consumption. In fact, modeling indicates that our proposal will cause the additional retirement of just 700 megawatts of existing coal-fired generating capacity (approximately equivalent to one medium-large power plant)—again relative to base-case projections—between now and 2020.

While early efforts to limit greenhouse gas emissions need not and, in the Commission's view, should not create undue hardship for the coal industry, it is clear that the industry will need to evolve to improve its competitiveness in an increasingly carbon-constrained world. The key is to develop coal technologies that are compatible with the need to reduce greenhouse gas emissions and that also address other public health and environmental concerns currently associated with conventional pulverized coal plants. The Commission sees great promise for achieving these objectives through integrated gasification and combined cycle (IGCC) coal technology, which—besides having lower pollutant emissions of all kinds—can open the door to economic carbon capture and storage. In fact, we believe the future of coal and the long-term success of future greenhouse gas mitigation efforts may hinge to a large extent on whether IGCC technology can be successfully commercialized and deployed over the next twenty years. Our complete report includes a detailed description of the potential of this technology, including its potential as a means for someday producing clean low-carbon liquid fuels suitable for use in the transportation sector, as well as a discussion of the financial and technological challenges that must be overcome to give coal IGCC a chance to prove itself in the marketplace. To help overcome these obstacles we propose a substantial increase in federal support for IGCC and other promising advanced coal technologies. Specifically, the Commission recommends that the federal government:

- Provide up to $4 billion over ten years to support the early deployment of roughly 10 gigawatts of sequestration-ready IGCC plants.
- Provide support for the commercial-scale demonstration of geologic carbon storage at a variety of sites with an investment of $3 billion over ten years.

In sum, the Commission firmly believes that the best future for coal lies not in continued paralysis on the issue of climate change, but in carefully designed policies that both effectively reduce climate risks and do so in a manner that helps the industry adapt and even thrive. That the United Mine Workers of America, an organization which we consulted frequently and extensively throughout our deliberations, has expressed support for the Commission's report and recommendations provides considerable grounds for optimism that it is possible to do both.

Question 2. Why is the NCEP proposal so modest?

Answer. As I noted in my testimony and in several of the foregoing responses, the Commission recognized from the outset that progress on climate change was not going to be possible in this country unless Congress and the public could be convinced of two things: first, that reducing greenhouse gas emissions could be achieved without harming the U.S. economy or putting U.S. businesses at a competitive disadvantage and second, that all countries with major emissions would soon join the United States in doing their fair share to implement reductions. The modesty of our proposal reflects an appreciation for the importance of these constraints. It also reflects an appreciation of the extent to which significant uncertainty on all sides of the climate debate, but most notably with respect to the consequences of current emissions trends and the costs and benefits of mitigation, argues for a gradual and flexible approach. Commission members are well aware that the emissions reductions required on a worldwide basis to stabilize atmospheric concentrations of greenhouse gases far exceed the level of reduction that would be achieved by the policies we have proposed for implementation over the next 10 to 20 years. As such we have never advertised our recommendations as a "solution" for climate change. Our goal, rather, was to design an approach that would allow the United States to take an initial step domestically while simultaneously establishing a robust policy architecture that could evolve over time to reflect changes in scientific understanding, technology development, and prospects for collaboration with other nations. Or as we put it in our report:

> "[T]his proposal should be understood as an initial domestic step in the long-term effort to first slow, then stop, and ultimately reverse current emission trends. In its structure and stringency, the Commission's proposal is designed to encourage the timely initiation of what will necessarily be a phased process. The Commission believes that this approach is more pragmatic and ultimately more effective than years of further legislative stalemate in pursuit of a more aggressive initial goal." (National Commission on Energy Policy, Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges, December 2004, p. 19)

RESPONSES OF HOWARD GRUENSPECHT TO QUESTIONS FROM SENATOR BINGAMAN

Question 1. The U.S. spends a significant amount of money on R&D into non-carbon and low-carbon technologies. How does this amount compare to our overall economy, our total spending on energy, and our total greenhouse gas emissions? Are other countries spending comparable amounts based on their size and emission levels?

Answer. The most recent year for which data are available for all of the domestic parameters requested above is 2003. For fiscal year 2003, Federal spending for programs in the Climate Change Technology Program was $2,555 million. For calendar year 2003, U.S. gross domestic product was $11,004 billion, energy expenditures were $751.7 billion, and total net greenhouse gas emissions were 6,072.2 million metric tons CO_2 equivalent. Therefore, Federal spending on climate-change technologies was 0.023¢ per dollar of GDP, 0.34¢ per dollar of energy expenditure, and 42.1¢ per ton of CO_2 Eq. Reliable data on government expenditures for climate change-related technologies are not readily available for other countries.

Question 2. Roughly how large an R&D investment do you believe is needed at this time, given that radically new technologies will be required in the future to address climate change? Are current energy R&D funding levels adequate, or do you think additional resources are required?

Answer. In 2005, the Federal Government plans to invest nearly $2 billion in climate change science and nearly $3 billion in climate change technology research, development, and deployment, including voluntary partnerships. Funding for these activities is adequate.

Question 3. In the EIA's analysis of the NCEP climate change proposal, was it important to know where in the energy system the point of regulation would be located? How was the point of regulation handled for the purposes of your analysis? Please describe what impact the point of regulation has on overall program effectiveness and discuss what bearing it has on your analysis.

Answer. The cost and effectiveness of any regulations depend partially on how they are implemented. ETA's analysis does not include the implementation costs (i.e., monitoring, verification, and management costs) of the NCEP cap-and-trade proposal for either the public or private sector, primarily because the implementation processes to be used are generally unspecified in the NCEP report. The actual costs of the NCEP proposal could be higher if the implementation process hinders the development of a fully functioning and efficient market for permits.

The NCEP climate proposal, a cap-and-trade system with a safety-valve price on GHG permits, is loosely modeled after the power plant SO_2 cap-and-trade program created in the Clean Air Act Amendments of 1990. This program generally has very low transactions costs. However, the NCEP proposal is more complex and difficult to manage because of the larger number of entities potentially affected. In EIA's analysis, a permit fee, based on the carbon content of the fuel, is reflected in the fuel cost at the point of consumption and all affected consumers are assumed to directly participate in the permit transactions. From an implementation perspective, however, it is impractical to expect many of the residential, commercial, and small industrial end-users to actually trade in permits. It is far more likely that the permit purchases and transactions would be regulated, managed and monitored at major emitters and major distribution points (marketers and distributors) in the energy market.

Question 4. In the ETA's analysis of the NCEP climate change proposal, was it important to know whether, how, and to what extent emission allowances would be allocated? How was allowance allocation handled for the purposes of your analysis? Please describe what impact the allowance allocation scheme has on overall program effectiveness and discuss what bearing it has on your analysis.

Answer. EIA's analysis assumed that the tradable permits allocated to the Federal Government (5 percent of the total between 2010 and 2012, then rising to 10 percent in 2022 and thereafter as specified in the NCEP recommendations) were publicly auctioned. The government also receives the safety value price for all permits that are purchased in excess of the emissions target for the cap-and-trade program. All other permits are allocated to emitters in proportion to their historical emissions.

EIA calculates that the projected cumulative discounted Federal revenue equals the cumulative discounted expenditures in 2022. Beyond 2022 any excess revenues collected are assumed to flow to the U.S. Treasury. Although EIA did not consider alternative allocation schemes, if the percent of tradable permits allocated to the Federal Government were higher, more revenues would flow to the U.S. Treasury and the point of "fiscal neutrality" would occur sooner.

ETA's analysis assumes that emission permits that are allocated to emitters are "grandfathered" based on historical utilization. A different allocation of permits would generally not affect the efficiency of the program, but it would change it's distributional impacts.

Question 5. Please reflect on the recent analysis you conducted for Senator Inhofe on the impacts of higher natural gas prices—among other things—on the NCEP's climate change proposal. Was the safety valve effective in keeping overall program costs down when confronted with the higher costs in this sensitivity case?

Answer. Senator Inhofe requested that EIA prepare sensitivity runs based on the full National Commission on Energy Policy (NCEP), Cap-Trade (with safety valve), and No-Safety (greenhouse gas cap and trade policy without safety valve) cases from our report using the natural gas price and availability assumptions in the *Annual Energy Outlook 2005* (*AEO2005*) "restricted natural gas supply" case, and assuming 25 and 50 percent fewer non-carbon dioxide emission reductions were available for purchase at a given greenhouse gas permit price.

We prepared three groups of four model simulations. Each group includes the comparable case from the earlier analysis of the NCEP proposals done at the request of Senator Bingaman, along with three sensitivity cases as stipulated by Senator Inhofe above.

We found that the alternative assumptions about natural gas supplies and the availability of non-CO_2 greenhouse gas emissions reductions have fairly small effects on the estimated incremental impacts of the NCEP's recommendations. The higher natural gas prices that result from the *AEO2005* restricted natural gas supply assumptions tend to lower overall energy demand and make non-fossil fuels like renewables and nuclear more attractive, even without the NCEP's recommended appliance and building efficiency standards, technology incentives, and greenhouse gas cap and trade programs. As a result, the incremental costs of complying with the NCEP recommendations are generally lower with these alternative assumptions even though the absolute level of economic performance, both with and without the cap-and-trade program, is adversely impacted by the reduced availability of natural gas in the restricted supply scenarios.

The assumptions about the availability of reductions in the emissions of non-CO_2 greenhouse gases are only important when the NCEP's recommended greenhouse allowance price safety valve is not in effect. When the safety valve is in effect, the emissions reductions coming from non-CO_2 gases are lower with the alternative availability assumptions, but there is little impact on energy markets because the greenhouse gas allowance price is capped, limiting the impact of the NCEP's capandtrade proposal.

RESPONSES OF HOWARD GRUENSPECHT TO QUESTIONS FROM SENATOR CORZINE

Question 1. I understand that your estimate of the economic impact of the NCEP proposal is that it would change our GDP in 2020 by a very minimal amount.

Answer. In 2000 dollars, real GDP in the NCEP case is expected to be $10 billion lower (0.1 percent) in 2010 and $35 billion lower (0.2 percent) in 2020 relative to the reference case. Consumption of goods and services per household falls by approximately $66 (0.1 percent) in 2010 and $273 (0.3 percent) in 2020. The consumer price index (CPI) rises by 0.2 percent in 2010 and by 0.4 percent in 2020. The inflation rate, as measured by the growth rate of CPI, increases by about 0.2 percent point in 2010 and by less than 0.1 percent point in 2020. The implementation of higher CAFE standards raises the average price of new light-duty vehicles by approximately four percent, with a decrease in sales of approximately four percent.

If only the cap-and-trade system is put in place (the Cap-Trade case), real GDP is expected to be $9 billion lower (0.1 percent) in 2010 and $17 billion lower (0.1 percent) in 2020 relative to the reference case. Consumption of goods and services per household falls by approximately $45 (0.1 percent) in 2010 and $78 (0.1 percent) in 2020. The consumer price index (CPI) rises by 0.2 percent in 2010 and by 0.5 percent in 2020. The inflation rate, as measured by the growth rate of CPI, increases by about 0.2 percent point in 2010 and by less than 0.1 percent point in 2020.

The relative size of these estimated impacts is, of course, in the eye of the beholder.

Question 2. Given the urgency of the global warming problem, what more can we do, beyond the NCEP proposal without, in the words of the Sense of the Senate resolution that we adopted last month, "significantly harming" the U.S. economy?

Answer. The Energy Information Administration (EIA), consistent with its statutory mission, does not develop or advocate any particular energy policy or environmental policies. One key way to minimize the impact on the economy of policies Congress or the Administration might wish to implement is to provide sufficient lead time to allow the various parts of the economy—consumers, business, and government—to change practices on a gradual steady basis rather than abruptly. Prospects for a smooth adjustment to policy changes are also enhanced when affected parties have the expectation that the newly implemented policies will be long-lived in order to have a lasting effect on behavior.

RESPONSE OF HOWARD GRUENSPECHT TO QUESTION FROM SENATOR SALAZAR

Question 1. Dr. Gruenspecht, in April 2005, the Energy Information Administration (ETA) released a report analyzing the policy recommendations contained within the 2004 National Commission on Energy Policy (NCEP) report entitled, "Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges." Since this analysis was published, the U.S. Senate passed a "Sense of the Senate" resolution calling for mandatory limits and incentives to slow, stop, and reverse the growth of greenhouse gas emissions in a manner and at a pace that will not significantly harm the economy and will encourage comparable actions by other countries.

In order to evaluate the full range of potential policies that would be compatible with the resolution, I request that the EIA build on its analysis to date by running a number of additional intensity target and safety valve scenarios. I note that EIA has been able to respond quickly to other Senators' analytical requests following the April report, and I request a similarly prompt response to this letter.

The analysis in the April 2005 report included a greenhouse gas (GHG) emissions intensity reduction program with a GHG intensity improvement of 2.4 percent per year between 2010 and 2019 and 2.8 percent per year between 2020 and 2025, and with a safety-valve permit price starting at $7 per metric ton CO_2 equivalent in 2010 nominal dollars and increasing by 5 percent annually up to $14.55 in 2025.

I request an additional analysis that evaluates a range of intensity improvements and safety-valve combinations. This analysis should include additional intensityimprovement/safety-valve combinations with intensity improvements ranging from 2.6 to 4.0 percent per year and safety valve values ranging from $10 to $35 (in 2010 nominal dollars, rising five percent per year). The purpose of this analysis would be to draw out the impacts of alternative policies. The different combinations run should allow policy makers to evaluate the impact of changing the safety valve price through this range given the base case intensity improvement (2.4 percent through 2020 and 2.8 percent thereafter), and to evaluate the impact of increasing the intensity improvement through this range in combination with various safety valve prices. Each of these combinations should be analyzed under both the base case and high technology assumptions.

This report should include estimates of the same environmental and economic indicators from the previous report, including but not limited to supply estimates (by fuel), GHG emissions, GDP and employment.

I request that you complete these analyses and report them to me and other members of this Committee by December 1, 2005.

Answer. EIA has met with Dr. John Plumb of your staff to discuss an approach to addressing this request.

RESPONSE OF HOWARD GRUENSPECHT TO QUESTION FROM SENATOR AKAKA

Question 1. The EIA analysis shows that three of the National Commission on Energy Policy's proposals will have the greatest effect on energy demand, use, and consumption in the U.S.—the cap and trade program, the increase in automobile fuel efficiency standards, and the new building and appliance efficiency standards. As far as economic impacts go, your testimony indicates that although costly, the changes will not affect average economic growth rates for the 2003 to 2025 time frame.

It appears from your analysis that fuel economy standards for transportation are essential for the rest of the cap-and-trade policy. They drive down demand and offset the cost of permits for the cap-and-trade system. Would you agree that to be successful, the carbon emissions from the transportation sector must be included in any cap-and-trade control policy?

Answer. It is generally true that the least costly approach to meeting any national greenhouse gas emissions intensity target is to include as many of the energy consuming sectors as possible in the cap-and-trade system, including the transportation sector. For any specific emissions target, the more expansive the market to which a GHG cap-and-trade policy applies, the less costly such a policy is to implement.

Transportation fuel consumption produces approximately one third of all combustion-related carbon dioxide emissions. In that sense, the transportation market is an important sector to incorporate in any carbon dioxide emission control strategy. There are three ways to reduce carbon dioxide emissions in the transportation sector: (a) through a capand-trade system which adds to the cost of using fossil fuels based on the carbon dioxide emitted, (b) through the use of standards (i.e., Corporate Average Fuel Economy (CAFE)), or (c) a combination of standards and a cap-and-trade system.

EIA studies have shown that carbon dioxide permit prices that are comparable to those under the NCEP cap-and-trade program would have negligible impacts on transportation fuel consumption. The result suggests that the transportation sector is not expected to be a major source of low cost GHG reductions. The NCEP permit price cap of $8.50 per ton carbon dioxide translates into an increase of about $0.08 per gallon in the delivered gasoline price. Carbon dioxide permit prices would need to rise to much higher levels to significantly affect consumer choices for light duty vehicles and fuel consumption. Light duty vehicle purchase patterns have only recently begun to shift in response to the increase in fuel prices. It is useful to note that an increase of 1 dollar per gallon of gasoline corresponds to a carbon dioxide permit fee of over $110 per ton carbon dioxide or $400 per ton carbon.

Fuel economy standards are a more direct way to limit petroleum fuel use, a goal that is related to, but distinct from, the goal of GHG reduction. However, consumer purchase patterns have shown that at prices under $2 per gallon, consumers value horsepower, safety and size more than efficiency. Fuel economy standards that override consumer preferences could engender a significant welfare cost.

RESPONSES OF HOWARD GRUENSPECHT TO QUESTIONS FROM SENATOR FEINSTEIN

Question 1. Could you explain the correlation between the level of emissions and the "safety valve" in the National Commission on Energy Policy's proposal? Specifically, how would the emissions level change over time at various levels of the price cap?

Does the price cap of $7 per ton lead to a stopping and reversal of emissions growth? Did you analyze alternative safety valve prices?

For example, what happens if we increase the price to $15, which is the level of the Canadian price cap?

What happens if we increase it to $30, roughly the level that emissions allowances are trading for in the European Union this week?

Answer. The greenhouse gas intensity target proposed by the NCEP implies an annual greenhouse gas (GHG) emissions target into the future. All energy users bear the cost of holding emissions permits equal to their greenhouse gas emissions in each year. Using a cap-andtrade system, a market-clearing emissions permit price is developed at which the energy market would take sufficient action to limit emissions to meet the desired GHG target. Since banking of permits is permitted in the NCEP proposal, some energy consumers may "over-comply" in earlier periods when cost is relatively low so that they can use the allowances later or sell them to others with a higher implicit compliance cost. As it does, the permit price rises until it reaches the safety valve price. When the permit price exceeds the safety valve price, some buyers will purchase permits from the Government at the safety-valve price rather than undertake costlier actions to reduce emissions. ETA's analysis projects that the NCEP cap-and-trade proposal would slow but not stop the growth of greenhouse gas emissions. ETA projects that a safety valve price of $7 per ton would not stop or reverse emissions growth in the United States for the 2010 to 2025 period.

EIA analyzed one additional case as a sensitivity to determine what allowance prices would be necessary to reach the GHG emissions targets through 2025 as prescribed by the NCEP report. The allowance price required to reach the NCEP emissions target, which itself allows for some growth in emissions even without consideration of the "safety value" feature, was about $15 per metric ton of carbon dioxide equivalent in 2015 and $35 per ton in 2025. The necessary permit prices to reach the NCEP emissions targets are generally higher when the cap-and-trade program is implemented without the other NCEP policies or if reductions in non-energy-related GHG emissions prove to be more costly than suggested by the EPA-provided abatement curves used in ETA's study.

Question 2. Under the National Commission on Energy Policy's proposal, what happens when a covered entity uses the safety valve rather than lowering emissions? What is done to ensure that emissions are actually reduced?

Answer. When a covered entity purchases permits from the Federal Government instead of making changes to its use of energy, the actual emission levels will exceed the NCEP targets. Implicitly, the target is being relaxed in order to avoid the need for higher-cost abatement actions.

Question 3. Under the Commission's proposal, a company could pay the $7/ton fee instead of reducing the greenhouse gases. So, in the end, is there really a firm cap on emissions?

Answer. Under the safety valve provision specified in the NCEP cap-and-trade proposal, there is no absolute cap on greenhouse gas emissions. However, when the permit price rises to the safety valve level, fossil fuel users and other GHG emitters continue to receive a price signal to reduce their emissions relative to the level of economic activity.

Question 4. What policy options do you recommend to correct this [safety valve issue] so we can still make environmental progress?

Answer. Because the Administration does not support the NCEP proposal, DOE is not in a position to offer policy recommendations for improving it.

Question 5. Has anyone looked at the cost of inaction—in other words, what the impact will be to the economy to not curb emissions? I'm thinking specifically of costs related to:

- health care due to dirtier air,
- insurance costs due to more intense storms,
- government emergency relief services,
- the costs of alternative sources of water in the west as the snow pack decreases,
- the costs of protecting homes, businesses and highways from rising sea levels,
- farm payments due to decreased agriculture output,
- and what the potential impact all of those increased costs will have on economic growth.

Answer. Consistent with its statutory mission and expertise, EIA provides only estimates of the economic and energy sector impacts of imposing energy-related environmental policies, such as those considered in the NCEP proposal, an analysis is requested by Congress or the Administration. Some of the issues raised in your question have been addressed in the scientific literature and in various assessment reports.

APPENDIX II

Additional Material Submitted for the Record

UNIVERSITY OF OTTAWA,
FACULTY OF SCIENCE,
Ottawa, Ontario, Canada, July 18, 2005.

Hon. PETE V. DOMENICI,
Chairman, Committee on Energy and Natural Resources, U.S. Senate, Washington, DC.

DEAR MR. CHAIRMAN: I respectfully request that the attached articles be entered into the committee record.* I conduct research on past climates in the Arctic, and feel the results of my group's work is of relevance to your hearing.

The enclosed research publication documents our discovery of new evidence for past warm periods in the Arctic. The material we use is a newly discovered mineral deposit found in permafrost regions, and which grew some 10,000 years ago. It is similar to cave deposits that have been extensively used to reconstruct past temperatures in continental settings. However, this material is formed by bacterial colonies that grow under conditions of climatic improvement. It shows that the average summertime temperature at that time was several degrees warmer than today.

The relevance of this work, as well as other studies that document a warm early Holocene climate in the Arctic, is that it emphasizes that climate change is both natural and dramatic. Further, the fauna and flora of the Arctic survived these very warm periods, and will certainly survive the natural climate warming that we have observed over the past century.

I am fully in favor of decreased emissions in order to improve air quality and to reduce energy demands. However, Kyoto and any similar treaty that would target CO_2 on the basis of curtailing global warming is fundamentally flawed. CO_2 is a very, very minor greenhouse gas that has never been shown to have an impact on climate. Energy and emissions policies to be adopted by the U.S.A and other countries must be based on factual science. We are not affecting climate, nor can we control climate. It is driven by solar activity, and amplified by water vapor. CO_2 is a nutrient for plants.

I hope that this may help with your committee's good work,

Sincerely,

IAN CLARK,
Professor, Isotope Hydrology and Paleoclimatology.

[Enclosures.]

UNIVERSITY OF VIRGINIA,
Charlottesville, VA July 19, 2005.

Hon. PETE V. DOMENICI,
Chairman, Committee on Energy and Natural Resources, U.S. Senate, Washington, DC.

DEAR SENATOR DOMENICI: Along with this letter, I am sending you an article from the refereed scientific literature entitled "Revised 21st Century Temperature Projections," authored by myself and three colleagues at the University of Virginia.*

The article demonstrates that likely temperature changes in this century are going to be near the low end of projections made by the United Nations' Intergovernmental Panel on Climate Change (IPCC). This substantially reduces the prospect of disastrous climate change and increases the time horizon for development of new energy technologies. The IPCC projections are largely warmer because of unrealistic

* Retained in committee files.

assumptions about carbon dioxide increases, and their assumption that the mathematical form of the large family of climate models, which represents scientific consensus, is wrong. These models share a common characteristic: warming, once initiated by human activity, tends to take place at a constant rate.

I ask that you place this letter and the following article in the record as material relevant to the Energy and Natural Resources Committee hearing on July 21, 2005.

Sincerely,

PATRICK J. MICHAELS,
Professor of Environmental Sciences.

[Enclosure.]

OREGON STATE UNIVERSITY,
Corvallis, Oregon, July 19, 2005.

Hon. PETE V. DOMENICI,
Chairman, Committee on Energy and Natural Resources, U.S. Senate, Washington, DC.

DEAR SENATOR DOMENICI: I would like to submit the two attached articles for inclusion in the public record for the hearing on Arctic climate on Thursday, July 21. One article is a review of the recent Arctic Climate Impact Assessment and the second an overview on trends in Arctic sea ice.

By way of introduction, please allow me to state that I have been active in meteorology and climatology since 1971 and have been recognized by the American Meteorological Society as a Certified Consulting Meteorologist. Since 1989 I have served as State Climatologist for Oregon, and I was a two-term President of the American Association of State Climatologists. My qualifications to comment on climate studies are very strong.

The views expressed in the attached articles are my own and do not necessarily represent the policy of the State of Oregon nor my employer, Oregon State University.

Sincerely,

GEORGE H. TAYLOR,
Certfiied Consulting Meteorologist.

[Enclosures.]

THE ARCTIC CLIMATE IMPACT ASSESSMENT—DOES IT REPRESENT A SIGNIFICANT BREAKTHROUGH IN OUR UNDERSTANDING OF THE ARCTIC?

Recently the *Arctic Climate Impact Assessment (ACIA)* report was released by the Arctic Council. The report documents significant ecosystem response to surface temperature warming trends that occurred in some areas since the mid-19th century and in the last thirty years. Among the conclusions of the report are:

- Annual average temperature in the Arctic has increased at almost twice the rate of the rest of the world.
- Winter temperatures in Alaska and western Canada have increased about 3-4 deg C over the past half century, with larger increase projected in the next 100 years.
- There has been widespread melting of sea ice and glaciers. The average extent of sea-ice cover has declined by 15-20% over the past 30 years.
- There has been increased precipitation, shorter and warmer winters, and decreases in snow cover.
- The area of the Greenland Ice Sheet that experiences some melting has increased about 16% since 1979.

These are just a few of dozens of conclusions, some of which involve effects plant and animal populations, others which describe consequences to humans (some beneficial, but most detrimental). Because the ACIA is so lengthy, I have not yet had a chance to thoroughly examine it. But based on a review of the Executive Summary (26 pages in length) and Conclusions (29 pages), I have been able to compare the ACIA statements with the conclusions of scientists studying the Arctic, from peer-reviewed journal publications. One of these days I'll get through the much longer Overview Report and perhaps update this analysis.

Is the ACIA a breakthrough climate assessment? Does it faithfully capture the essence of climate change in the Arctic? Or is it just another doom-and-gloom report from the international climate community? Following is an examination of climate behavior in the Arctic over the last couple centuries (and earlier).

ARCTIC AIR TEMPERATURES

Naurzbaev, et al. (2002) created a proxy temperature data set spanning nearly 2,500 years for the Taimyr Peninsula of northern Russia, all of which is poleward of 70°N. The authors studied tree rings-widths of living and deceased larch trees. They reported that "the warmest periods over the last two millennia in this region were clearly in the third, tenth to twelfth and during the twentieth centuries." The first two, they claim, were warmer than those of the last century. Twentieth century temperatures appeared to peak around 1940.

Chylek, et al. (2004) analyzed Greenland air temperatures over the last 100 years. At coastal stations, "summer temperatures, which are most relevant to Greenland ice sheet melting rates, do not show any persistent increase during the last fifty years." The peak coastal temperatures occurred in the 1930s, followed by significant cooling, followed by warming; but current temperatures "are about 1° C below their 1940 values." In the highest elevations of Greenland's ice sheet, "the summer average temperature has decreased at the rate of 2.2° C per decade since the beginning of the measurements in 1987."

The warm period in the first half of the 20th century, prior to the big increases in greenhouse gases, saw very rapid warming—even though CO_2, reputed by many to be the most significant driver of temperature change, rose very little. In fact, during the decade of the 1920s at the coastal stations, "average annual temperature rose between 2 and 4° C [and by as much as 6° C in the winter] in less than ten years." The authors conclude that conclude that "since there was no significant increase in the atmospheric greenhouse gas concentration during that time, the Greenland warming of the 1920s demonstrates that a large and rapid temperature increase can occur over Greenland, and perhaps in other regions of the Arctic, due to internal climate variability such as the NAMINAO [Northern Annular Mode/North Atlantic Oscillation], without a significant anthropogenic influence." Further, "the NAO may play a crucial role in determining local Greenland climate during the 21st century, resulting in a local climate that may defy the global climate change." Contrary to the ACIA statements, CO_2 increases would seem to have little or no effect on Greenland climate.

The instrumental record demonstrates a consistent trend as well. Polyakov, et al. (2002, 2003b) studied a large area in the Arctic and created a history of temperature from 1875. They report that temperature peaked in the late 1930s, with 1937 the warmest single year. Since that time, there was a cooling, then a recent warming, but current temperatures have yet to reach the levels observed 65 years ago.

I decided to create some temperature plots myself. Using data from the Global Historical Climate Network (GHCN) data base, I created graphs displaying annual average temperatures for all stations north of 70°N. Figure 1* shows trends from 1970 through 2003, a period with significant warming—about 1.5° C in 33 years, the equivalent of 4.5° C per century, which fits right in with the ACIA's projections.

Now take a look at Figure 2, showing the trend from 1934 to 2003. Significant cooling occurred through about 1964, followed by a leveling off and then a slow rise, but temperatures remain cooler than they were in the 1930s.

Finally, in Figure 3 we see the entire period, back to 1880. Overall, there is about a 2° C warming, but this is because the record starts with a very cold period and ends on a warm one.

Fitting a linear trend (as shown) to such an oscillatory time series strikes one as highly inappropriate!

These results are nearly the same as those of Polyakov, et al. (2002).

Conclusion: while temperatures appear to have warmed in the last 40 years, a longer viewpoint shows much warmer temperatures in the 1930s and 1940s, apparently even warmer than those today.

SEA ICE IN THE ARCTIC

Grumet *et al.* (2001) created a record of sea ice conditions in the Baffin Bay region of the Canadian Arctic going back 1,000 years. They concluded that the 11th through 14th centuries saw reduced sea ice, but that ice extent was greater over the next six centuries. The last century has shown that "sea-ice conditions in the Baffin Bay/Labrador Sea region, at least during the last 50 years, are within 'Little Ice Age' variability," despite several periods of warmer temperatures. The authors added an interesting statement, as well, stating that the sea ice cover history of the Arctic "can be viewed out of context because their brevity does not account for

* Figures 1-4 have been retained in committee files.

interdecadal variability, nor are the records sufficiently long to clearly establish a climate trend."

For an area in the Greenland Sea, *Comiso et al. (2001)*, used satellite images to assess the size and character of the Odden ice tongue, a 1,300 km long feature, from 1979 to 1998. They were also able to infer its character back to the early 1920s using temperature measurements. The authors stated that there has been no statistically significant change in any of the parameters studied over the past 20 years. However, the proxy record several decades further into the past reveals that the ice tongue was "a relatively smaller feature several decades ago," apparently as a result of warmer temperatures.

Omstedt and Chen (2001) identified a proxy record of the annual maximum coverage of Baltic sea from 1720 through 1997. They stated that there was a sharp decline in sea ice in about 1877. There was also greater variability in sea ice extent in the first 150 years of the record, which was colder, than in the warmer period of the last 100 years.

Jevrejeva (2001) reported on a longer Baltic sea ice data set from 1529 to 1990 for the port of Riga, Latvia. The time series included four climate eras: (1) 1530-1640, with warming accompanied by earlier ice break-up (by 9 days/century); (2) 1640-1770, a cooler period with later ice break-up (5 days/century); (3) 1770-1920, with warming and a tendency toward earlier ice break-up (15 days/century); and (4) 1920-1990, a cooling period with later ice breakup (by 12 days/century).

Conclusion: Arctic sea ice has undergone significant changes in the last 1,000 years, even before the mid-20th century "greenhouse enhancement." Current conditions appear to be well within historical variability.

OCEAN CONDITIONS

Polyakov, et al. (2003a) were anxious to assess reports of "extraordinary change in the Arctic Ocean observed in recent decades" made by various parties. To investigate these claims, they used temperature and salinity measurements in made winter in the central Arctic Ocean near Russia in 1973-79. They also employed 40 years of summer and winter observations in the Laptev Sea.

The authors concluded that earlier reports of rapid Arctic warming "considerably underestimates variability." Their new analyses "place strong constraints on our ability to define long-term means, and hence the magnitudes of [air and sea temperature] anomalies computed using synoptic measurements from the 1990s referenced to means from [earlier] climatologies."

Conclusion: ocean temperature histories, like those of air temperature and sea ice, display marked variability. We are in danger of oversimplifying the historical trends and misrepresenting the future if we simply assume "the Arctic Ocean is warming up and will continue to do so."

DISCUSSION

Oddly, the ACIA does a very poor job of documenting its sources of information. For such an ambitious document (it is hundreds of pages long, with stunning graphics and a very professional appearance) its science consists primarily of blanket statements without any sort of reference or citation. Were any of the references listed above considered by the ACIA team. It appears doubtful.

The ACIA appears to be guilty of selective use of data. Many of the trends described in the document begin in the 1960s or 1970s—cool decades in much of the world—and end in the warmer 1990s or early 2000s. So, for example, temperatures have warmed in the last 40 years, and the implication, "if present trends continue," is that massive warming will occur in the next century. Yet data are readily available for the 1930s and early 1940s, when temperatures were comparable to (and probably higher than) those observed today. It would appear prudent to use the longest reliable record for assessing trends.

It is also inadvisable to employ the use of linear trends to represent time series which are cyclical in nature. The character of a trend line in a data set like the one shown in Figure 3 is largely a function of the starting and ending points selected.

CONCLUSIONS

Recently National Geographic devoted an issue to "Global Warming." Reading the ACIA brought back memories of the NG publication, and brought to mind the overall comment I made upon reviewing it: slick and beautiful but very one-sided. That pretty much sums up my feelings about the ACIA, based on what I have seen so far: nice graphics but bad science.

TRENDS IN ARCTIC SEA ICE

According to the Arctic Climate Impact Assessment, published in 2004 and 2005, there has been widespread melting of sea ice and glaciers in the Arctic in recent decades; the average extent of sea-ice cover has declined by 15-20% over the past 30 years.

According to Environmental News Service (February 1, 2005), "Global warming will hit the Arctic harder and faster than the rest of the world and could cause the extinction of polar bears and other Arctic wildlife within 20 years, conservationists warn. 'If we don't act immediately the Arctic will soon become unrecognizable,' said Tonje Folkestad, climate change officer with WWF's International Arctic Program."

Many scientists, and a large number of journalists, have made similar claims. Below is an overview of Arctic climate science, based on reviews of scientific journal publications, which shows a very different picture.

SEA ICE IN THE SUB-ARCTIC

Grumet *et al.* (2001) created a record of sea ice conditions in the Baffin Bay region of the Canadian Arctic going back 1,000 years. They concluded that the 11th through 14th centuries saw reduced sea ice, but that ice extent was greater over the next six centuries. The last century has shown that "sea-ice conditions in the Baffin Bay/Labrador Sea region, at least during the last 50 years, are within 'Little Ice Age' variability," despite several periods of warmer temperatures. The authors added an interesting statement, as well, stating that the sea ice cover history of the Arctic "can be viewed out of context because their brevity does not account for interdecadal variability, nor are the records sufficiently long to clearly establish a climate trend."

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MOVING POLEWARD

Laxon, et al. (2003) were motivated by a "mismatch between the observed variability and that predicted by models." Unfortunately, the "sparseness of sea ice thickness observations" in the Arctic means that the "regional and interannual variability of sea ice thickness is entirely based on models of the Arctic." They found high-frequency interannual variability which runs counter to what the models say. In conclusion, "Until models properly reproduce the observed high-frequency, and thermodynamically driven, variability in sea ice thickness, simulations of both recent, and future, changes in Arctic ice cover will be open to question."

Polyakov, et al. (2002) studied sea ice cover over the Kara, Laptev, East Siberian and Chukchi Seas north of Russia. Sea ice cover trends were "smaller than expected" and "do not support the hypothesized polar amplification of global warming." In a later report, Polyakov et al. (2003b) stated that "long-term ice thickness and extent trends are small and generally not statistically significant"; in fact, "over the entire Siberian marginal-ice zone the century-long trend is only 0.5% per decade," or 5% per century."

A number of researchers have suggested that inflows of Atlantic water into the Arctic profoundly affect temperatures and sea ice trends in the latter ocean. Polyakov, et al. (2004) are among these. The first sentence of their paper states "Exchanges between the Arctic and North Atlantic Ocean have a profound influence on the circulation and thermodynamics of each basin." The authors attributed most of the variability to multidecadal variations on time scales of 50-80 years, with warm periods in the 1930s-40s and in recent decades, and cool periods in the 1960s-70s and early in the 20th century. These are associated with changes in ice extent and thickness (as well as air and sea temperature and ocean salinity). The most likely causative factor involves changes in atmospheric circulation, including but not limited to the Arctic Oscillation.

It is tempting to employ satellite data to estimate sea ice trends (see, for example, Parkinson, et al., 1999; and Parkinson, 2000). Granted, satellites are marvelous tools for such surveys, but their data sets are limited to only the last several decades. According to Schmith and Hansen (2003), trend studies of Arctic sea ice conditions "should be regarded with some care" since the period of satellite observations coincided with but one phase of a clear multidecadal oscillation. Studying observations for the period 1820-2000, the researchers used ice observations to estimate ice export in waters off Greenland. One parameter which shows multidecadal variability is the correlation between ice export and the North Atlantic Oscillation (NAO); see trends below. In recent decades there has been a strong correlation between the two, as there was in the 1930s-40s. During the 1960s-70s and from about 1870-1920 there were much lower correlations. This "casts doubt on the hypothesis of enhanced greenhouse effect being the cause" for recent NAO-sea ice correlations, according to Schmith and Hansen (2003).*

Rigor, et al. (2002) suggest that the Arctic Oscillation (AO) affects surface air temperatures and sea ice thickness over the Arctic in a profound way. Ice thickness responds primarily to surface winds changes caused by the AO, whose long-term trends are shown below.

Parkinson (2000) seems to have identified decadal or longer trends as well. The analysis described in that paper divided the Arctic into nine regions. In seven of the nine the sign of the trend "reversed from the 1979-1990 period to the 1990-1999 period," which is another reason to be cautious when evaluating relatively short data sets.

Holloway and Sou (2002) used data from "the atmosphere, rivers and ocean along with dynamics expressed in an ocean-ice-snow model." The authors warn against using any linear trend longer than 50 years due to multidecadal variability, which included "increasing volume to the mid-1960s, decadal variability without significant trend from the mid-1960s to the mid-1980s, then a loss of volume from the mid-1980s to the mid-1990s. They also suggest that changes in wind patterns play a large role in ice thickness changes and that "Arctic sea ice volume has decreased more slowly than was hitherto reported." In fact, "the volume estimated in 2000 is close to the volume estimated in 1950."

INTERDECADAL VARIABILITY

Again and again we see terms "decadal," interdecadal" or "multi-decadal" in describing Arctic sea ice conditions. You have seen the similarity of the NAO and AO and can view the long-term variability. Note that in the NAO and AO charts that 1970 (a starting point for many of the time series being mentioned) occurred at a time of minimum NAO and AO value.

Now consider a data set from the WARM part of the world, the Pacific Decadal Oscillation (PDO). Below annual values of the PDO. In the following chart I have plotted the NAO, AO and PDO together, with 19-year smoothing to show long-term trends. The final chart shows surface air temperature in the Arctic, from Polyakov, et al. (2002), showing striking multidecadal variations.

WHAT THIS TELLS US

If we want to understand variability of Arctic sea ice (and, for that matter, sea and air temperature) we should take our eyes off greenhouse gases, at least for a moment, and study multidecadal phenomena. We should also avoid the temptation of taking the last 20-30 years of data, computing a trend, and assuming that that trend will continue for 50-100 years. History tells us that long-term linear trends will not occur. In the words of Santayana, "Those who cannot remember the past are condemned to repeat it." Or make bad forecasts.

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*All graphs have been retained in committee files.

STATEMENT OF GLENN KELLY, EXECUTIVE DIRECTOR, ALLIANCE FOR CLIMATE STRATEGIES, WASHINGTON, D.C.

Mr. Chairman and Members of the Committee, the Alliance for Climate Strategies (ACS) appreciates the opportunity to submit the following statement for the record regarding the actions our member industries are taking to address climate and emissions issues.

ALLIANCE FOR CLIMATE STRATEGIES DESCRIPTION

ACS is a broad-based advocacy coalition of industry sectors created to:

- Exemplify the principle that voluntary actions are an effective means of reducing greenhouse gas (GHG) emissions.
- Demonstrate that the ingenuity and technological expertise of American industry can achieve meaningful reductions in GHG emissions.

Membership in the Alliance includes the following eight trade associations:

- American Chemistry Council.
- American Forest & Paper Association.
- American Petroleum Institute.
- American Road & Transportation Builders Association.
- Edison Electric Institute.
- Nuclear Energy Institute.
- National Mining Association.
- National Rural Electric Cooperative Association.

ACS members believe that a "do nothing" option clearly seems imprudent, especially when common-sense, cost-effective strategies are available that will support technology development and deployment while creating jobs and sustaining economic growth. Members of ACS also believe that the costs and consequences of a mandatory cap-and-trade program will severely impact every state and congressional district in the nation by raising household consumer costs and reducing job opportunities while doing little if anything to address the global nature of the climate issue.

Our statement will address the following four topics:

- Carbon Dioxide Emissions Trends (U.S. and Abroad).
- GHG Measuring and Reporting.
- Ongoing Voluntary Initiatives and Investment.
- Technology Research, Development & Deployment.

There often is a misperception that due to the general opposition to mandatory GHG emissions reduction caps, industry is doing nothing on the issue. Nothing could be farther from the truth. U.S. industries, in fact, have a well established and successful record of voluntary GHG management initiatives that is strong today and continues to grow. Government strategies and policies that provide investment stimulus to develop and deploy existing and new low-carbon and zero-carbon technologies will help to continue and expand this successful record of voluntary initiatives.

CARBON DIOXIDE EMISSIONS TRENDS (U.S. AND ABROAD)

The Energy Information Administration (ETA) reports that carbon dioxide (CO_2) accounts for approximately 85 percent of U.S. GHG emissions. The remainder includes the GHGs methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride. While all of these are important, it is easy to see why the focus is on CO_2; on a global warming potential basis it accounts for almost 85 percent of total U.S. GHG emissions. Because more than 95 percent of the CO_2 emissions come from energy, energy quickly becomes the focus for many people.

Looking at energy-related CO_2 emissions in round numbers, about one-third comes from transportation, a little less than one-third comes from industry, and a little more than one-third comes from residential and commercial sectors combined. These sector numbers include allocated electricity emissions. Roughly three-fourths of residential and commercial emissions are associated with electricity, while in the industrial sector, less than 40 percent is associated with electricity.

Looking at trends over 1990-2003 (see chart* above), U.S. GDP grew about 3 percent per year, but overall energy-related CO_2 emissions grew only 1.1 percent per year. CO_2 emissions from the residential and commercial sectors grew about 2 percent per year, while transportation grew less than 1.5 percent per year. But the big

*All charts have been retained in committee files.

message here is that industrial CO_2 emissions from energy actually declined—*that is, without mandatory GHG programs, industrial sector emissions were lower in 2003 than they were in 1990.*

Turning to global trends, a couple of key realities are evident. First, following a substantial drop in Eastern Europe/Former Soviet Union emissions with the collapse of the former Soviet Union just after 1990, emissions trends are now clearly upward in those countries. Second, developing country emissions were about 40 percent below those of industrialized countries in 1990 but by 2020 are projected to be more than 10 percent above developed country emissions. Third, driven largely by efforts by China and India to improve their citizens' standard of living, between 2000 and 2020 developing country CO_2 emissions are projected to increase by 71 percent, but developed country emissions increase by only 23 percent. Addressing global GHG emissions without involving the developing countries is really an exercise in futility.

Looking more closely at the E.U. major 15 countries, the chart below illustrates the report of the European Environmental Agency (EEA) evaluating whether the E.U.-15 countries are on track to meet their Kyoto Protocol commitments for 2008-2012. In the chart, the green-colored bars are positive and the red-colored bars are negative. Only the U.K. and Sweden are "green," and the remainder of this graphic is "red," meaning the EEA concludes that these countries are not on track to meet their burden-sharing targets.

Clearly, many of the E.U.-15 countries are way above the emission trends required to meet their targets. Additionally, the E.U. Emissions Trading System went into operation on January 1, 2005—even though some of the basic plans were yet to be completed—to say nothing of the institutions needed to administer the trading system. The message here is capping and actually reducing GHG emissions is a serious and difficult challenge in any country. Western Europe is having difficulty meeting its Kyoto Protocol commitments, and actions that have been too difficult to adopt thus far may well be required. And circumstances in the U.S. are far different from those in Europe. EIA projects West European population growth to amount to less than 10 million over 2000-2020. Contrast that with the U.S.—where population is projected to increase by about 60 million people by 2020—and one can quickly see the challenges that lie before us.

Based on data from ETA's *International Energy Outlook 2004*, the U.S. is making strong progress on reducing the carbon intensity of economic activity. Intensity reductions in Germany and the U.K. exceed those in the U.S., but Germany benefited from shutting down highly inefficient East German factories with reunification, and the U.K. had massive reductions in coal use by switching to natural gas. But U.S. reductions in the ratio of carbon (from energy) to GDP exceed those of the other Western European countries as well as Japan and Canada—all of whom have ratified the Kyoto Protocol. (See chart below.)

While the Europeans are struggling with their Kyoto Protocol requirements, some in the U.S. advocate GHG emissions caps. Proposals from Senators McCain and Lieberman and from Senator Bingaman are two such examples. One issue often overlooked is the sheer size of some of these cap and trade proposals.

Some invoke the success of the sulfur dioxide (SO_2 or acid rain) program as an argument for using GHG emission allowances. However, there are huge differences between the SO_2 program and the programs envisioned under current cap and trade proposals. First, there are commercially available end-of-the-stack control technologies for SO_2, but not for CO_2—at least until carbon capture and geologic storage becomes cost effective. Second, the SO_2 program covers only a single industry, while GHG cap and trade proposals would impact the entire U.S. economy. Third, the SO_2 program has about 9 million tons of allowances, while the McCain-Lieberman bill, as one example, has almost 6 billion tons of allowances, plus a complicated and uncertain number of "offsets." Fourth, the acid rain program had a market value of allowances of about $1.5 billion in 2003. But in 2010, "issued allowances" under the McCain-Lieberman bill would have a market value of $80-$115 billion, according to the EIA. By 2025, such a program would have a market value of $245-$278 billion. The magnitude of a McCain-Lieberman proposal is not often appreciated. A comparison of the acid rain program is noted in the following chart:

That is a quick overview of global GHG emission trends, what industry has accomplished over the past decade, and the real-world difficulties posed by mandatory programs. We would like to turn now to a discussion of voluntary reporting and measurement.

GHG MEASURING AND REPORTING

We would like to make it clear that U.S. industry is taking significant steps to measure and report emissions voluntarily, and we would like to highlight to the Committee some of the activities that ACS members are undertaking as participants in the Climate VISION program of the Department of Energy (DOE) (see below).

The first step in addressing emissions is learning to measure emissions accurately. Industrial processes are highly varied—ranging from complex systems to single units—and they use different types of fuels in different ways. Converting fuel usage to emissions requires careful collection and organization of data and selection of correct conversion factors. Industry is aggressively working to address these issues.

The first step in calculating emissions is adoption of a protocol. This is a plan or general outline of what type of data will be collected and how it will be combined. The second step—and probably the most important—requires developing methods that are specific to each industry. This involves identifying operations, establishing accounting boundaries, collecting data, and finding emissions factors. For diverse industries with varying operations, each of these steps is critical and must be carefully tested to assure that the method is accurate and that data collection is feasible. Once the method is established, spreadsheets can be created to facilitate the actual calculation.

We call the Committee's attention to an example from the oil and gas industry that shows how critical the methodology is in calculating emissions (see chart below).

This chart shows the variation that can occur in estimating emissions. Looking from left to right across the graph, API compared the methane emissions from an on-shore oil production facility using its *Compendium* and methods developed by Latin American Oil and Gas Industry (ARPEL), the Environmental Protection Agency (EIIP), the European exploration and production industry (E&P Forum), the Canadian industry (CAAP), and the United Nations Intergovernmental Panel on Climate Change (IPCC).

The results show that the various methods produced estimates of methane emissions that vary by more than *fivefold.* This clearly shows the variability in calculating emissions, especially emissions from non-combustion sources (the solid area on the bar chart). API is working to get its *Compendium* adopted as a single, comprehensive and consistent method for estimating GHG emissions from oil and gas facilities worldwide.

The forest products industry represents a different operating situation. At pulp and paper mills more than 90 percent of emissions come from stationary combustion of fossil fuels; thus, the emission factors proposed by the IPCC were a good starting point. In early 2001, the pulp and paper industry, working with its international counterparts, began a project to develop a global methodology for estimating GHG emissions. The resulting industry-specific calculation tools were based on protocols developed by World Resource Institute (WRI) and World Business Council on Sustainable Development (WBCSD) and were subsequently peer reviewed and adopted as the WRI/WBCSD pulp and paper mill module. The complete tools include a step-by-step description of the process and a spreadsheet to make the calculation process easy. The forest products industry also developed a similar tool for wood products facilities. This tool is also undergoing the WRI/WBCSD review process. Other industries—cement, aluminum, iron and steel, and mining—are creating similar modules based on the WRI/WBCSD protocol.

Finally, utilities currently report virtually all of their GHG emissions to the EPA under the Clean Air Act. Utilities that purchase fuel to generate electricity use a fairly consistent process. Thus, "continuous emissions monitors" applied to the stacks and estimated fuel-use data can be used to calculate CO_2 emissions. Using this approach, it is estimated that utilities are reporting 99.9 percent or more of their emissions to EPA. This information is published annually at the sector level by the EPA.

Starting in 1994, the power sector was one of the first to begin reporting of voluntary efforts under the Energy Policy Act of 1992 section 1605(b) program to the EIA. In 2003, the sector had reported about 261 million tons of CO_2-equivalent emission reductions from direct emission reductions, avoided emissions and sequestration. The level of reported reductions by utilities has increased almost every year since the program began. Power sector members plan to continue reporting their GHG emission reduction activities under the 1605(b) program. Other industries will be reporting emission reductions as part of their Climate VISION commitment.

ONGOING VOLUNTARY INITIATIVES & INVESTMENT

We would also like to highlight the voluntary programs and initiatives that member associations of ACS are undertaking as part of the Climate VISION program.

In 2002, President Bush challenged the nation to reduce its GHG emissions intensity 18 percent by 2012 through voluntary actions. As part of the President's strategy, he created the Climate VISION (Voluntary Innovative Sector Initiatives: Opportunities Now) program, housed at DOE. Under the program, industries—working with various federal agencies—commit to voluntarily reduce their GHG emission intensities. To date, 14 industry associations, representing more than 90 percent of U.S. industrial GHG emissions, have announced voluntary pledges and programs.

One of the most important tools for achieving the intensity reduction goal will be company activities. Some of these activities will occur through individual company initiatives, such as those under the EPA Climate Leaders program, and others through industry-wide initiatives, such as PowerTree Carbon Company. PowerTree Carbon Company is an initiative sponsored by 25 U.S. power companies—including investor-owned utilities and cooperatives—to plant trees in critical habitats in the Lower Mississippi River Valley to manage CO_2.

Yet another element of company activities will be the use of numeric goals to drive internal actions. The Climate Leaders website contains a partial listing of such actions.

Late last year, the power sector signed a memorandum of understanding (MOU) with DOE to achieve the equivalent of a 3-5 percent reduction in its carbon intensity by 2012. Actions under a work plan will include achieving credible, verifiable reductions in carbon intensity or offsets of GHGs through a range of individual company actions, industry-wide initiatives and cross-sector efforts. EEI members, for example, will work with their counterparts in the other power sector trade associations to help achieve this voluntary numeric goal.

In addition, NRECA and the Department of Agriculture earlier signed an MOU to identify and advance technologies that will help achieve the national goal. Initially NRECA is working with its members and the Agriculture Department to eliminate technical and market barriers to the use of low-emission renewable energy, such as agricultural waste-to-electricity, through the use of systems approaches and the development of decision-support tools.

Other ACS members have similar agreements, such as:

American Forest & Paper Association

AF&PA members plan to reduce their emissions intensity by 12 percent by 2012 through:

- Developing new, energy-efficient technologies that use renewables and biomass energy and that, if fully commercialized, could make the forest products industry energy-self sufficient.
- Increasing paper recovery for recycling, which avoids GHG emissions by keeping paper out of landfills.
- Enhancing carbon storage in forests, which remove CO_2 from the atmosphere and store it for long periods of time.
- Enhancing carbon storage in wood and paper products, which continue the process of withholding carbon from the atmosphere.

American Petroleum Institute

- 100 percent participation in Natural Gas Star and combined heat and power programs.
- 10 percent improvement in aggregate refinery energy efficiency over 2002-2012.
- Develop GHG management plans.

National Mining Association

- Reductions through research under DOE-NMA Industry of the Future program.
- Calculate industry efforts to sequester carbon on reclaimed mine lands.
- Develop voluntary reporting methodology.
- Additional reductions from coal mine methane recovery where feasible.

Industry has responded to the Climate VISION challenge. ACS members are taking actions that will result in real and substantial GHG reductions now, not in the future—and without the need for mandatory actions. Furthermore, industry is taking significant steps to measure and report emissions voluntarily, and we wanted to take this opportunity to tell you about some of the things that we, as members of Climate VISION, are doing.

TECHNOLOGY RESEARCH, DEVELOPMENT & DEPLOYMENT

All energy resources along with efficiency and conservation will be needed to meet our nation's growing demand for energy and electricity. It is important that we develop and put into commercial operation technologies that will allow us to use these resources with as low an emissions profile as possible.

One way that will allow our economy to grow with lower emissions is to continue to develop ways to use energy more efficiently. In the last 20 years, we have reduced the amount of energy we need for each dollar of GDP by 40 percent. This trend will continue on a nationwide basis, but to be more specific:

Many of the industries that are associated with ACS are working with DOE in a program called Industries of the Future, in which they are jointly funding research to make their operations more efficient. These projects are short term—they will have an impact in the next few years.

Cogeneration—a process where the waste heat that is produced when making electricity is captured and used—is a relatively new example of efficiency in action. And that is just the tip of the iceberg. It is only good business to produce more with less energy, and all industry is working toward that goal.

Some technologies, such as nuclear power and renewable technologies, have no carbon emissions, and it is important that public policies support, not constrain, their increased use.

Wind, solar and biomass are the most promising of the renewable technologies, and technological advancements are lowering the cost of these every year. The amount of electricity generated from wind power, although still small, has doubled since 2000. The use of solar and biomass is also increasing.

Now just a few words about nuclear power—our largest source of non-carbon-emitting electricity generation. The U.S. has 103 operating nuclear plants producing close to 20 percent of our electricity. In the absence of nuclear power, U.S. electric sector carbon emissions would be almost 30 percent higher, according to calculations by the Nuclear Energy Institute (based on data from EIA). Given the volume of carbon emissions prevented by nuclear power plants, it is clear that the U.S. cannot have a plausible long-term climate program without a growing contribution from nuclear power.

The electric power industry is moving forward with a program that will lead to construction of new nuclear plants in the U.S., and there is significant progress on that score. The licensing process has been overhauled, and the Nuclear Regulatory Commission is reviewing several new standardized designs. Three companies have submitted applications for early site permits, and two consortia are preparing applications for construction and operating licenses. And the Tennessee Valley Authority is leading a third consortium, evaluating the feasibility of building new nuclear plants at its Bellefonte site in Alabama. If all goes well, the nuclear industry will have units under construction by 2010 with significant numbers of new nuclear plants built during the next decade.

But, as mentioned previously, we need all forms of energy to meet future demands, and this means that we will continue to use all fossil fuels—coal, oil and natural gas—well into the future. Although we are working to minimize emissions from fossil fuel use, we also have to look at ways to capture and permanently store—or sequester—CO_2 emissions. In some instances, this can be done directly as the energy is used. In other cases, where CO_2 cannot be directly captured, we have to look at ways to offset emissions, for example, through the capture of CO_2 from the air and then storage of this CO_2 in forests, plants or grasses. This is terrestrial sequestration; in the short term, this is probably the best way to capture and store CO_2. Many of our companies have terrestrial sequestration programs that are on the ground and working now. The forest products industry is working to increase research on forest sequestration and has established the Forest Carbon Consortium to promote research on the potential of managed forests to store carbon and produce energy.

Storage of carbon in plant life is not the only way to go. Carbon can be stored in geologic formations on land and in the ocean. A number of companies in the industries represented by ACS members are part of the joint industry-government Regional Carbon Sequestration Partnerships that were started about two years ago with the goal of determining the most suitable technologies, regulations and infrastructure for carbon capture, storage and sequestration in each region of the country.

Internationally, our government formed the Carbon Sequestration Leadership Forum, which brings governments and industry from all over the world to share information and conduct joint research in order to find ways to sequester carbon more efficiently and cost effectively. ACS members are involved in this initiative.

Finally, DOE has initiated a joint government-industry research program to find safe ways to store carbon in geologic repositories. The Electric Power Research Institute (EPRI)—a research arm of the electric utility industry—has a pilot-scale test center for CO_2 capture and containment. EPRI has developed site-selection criteria for CO_2 sequestration, and is in the process of selecting a site to test long-term underground CO_2 storage.

We are also working on projects that will result in lower emissions when we use fossil fuels—in particular, coal and petroleum products. These projects are both short and long term. The Clean Coal Technology Industry-DOE partnership is well established—it started in 1986 to address SO_2 and nitrogen oxide issues. Over time, the program has evolved, and technologies, such as integrated gasification combined cycle (IGCC), have been developed to use our vast coal resource more cleanly—with lower emissions and more efficiency. This means lower CO_2 emissions for each unit of electricity produced. Many of these are new or very near-term technologies. These are important, as coal provides more than 50 percent of the electricity used in our country now and is expected to maintain this share in the future.

Industry is also working on research that will have benefits in the long term. For example, a number of coal and utility companies are involved with DOE in a project called FutureGen, which is an initiative to build the world's first zero-emissions coal-fired power plant. This will be a commercial scale IGCC plant that produces electricity and hydrogen. The CO_2 will be captured and sequestered. This is an important part of the Administration's effort to move our economy—over the long term—to a hydrogen-based economy. Hydrogen will be made from many fuels, including coal and natural gas.

There are a number of transportation initiatives that will result in reduced emissions over time. In the short term, the CO_2 diesel project that is just beginning will test the capability of using biofuels in large-scale mining operations in Nevada and Indiana. Utilities are working with DOE to develop and test a commercial hybrid work truck that will mean lower CO_2 emissions, and the automobile industry is an active participant in the Freedom Car project.

These examples are illustrative of the many research projects that are ongoing to develop technologies that will result in lower emissions in both the short and long term.

CONCLUSIONS

The often-stated claim that the U.S. industrial sector is not responsive to concerns about GHG emissions and climate change is unfounded. Indeed, the U.S. industrial sector, largely represented by ACS, is working to address emissions concerns through a variety of means—voluntary initiatives, government partnerships, and technology research, development and deployment. ACS members are proud of the achievements to date that are outlined above and look forward to more positive progress. No other sector of the U.S. economy can claim this level of progress.

Thank you, Mr. Chairman and Members of the Committee, for the opportunity to submit this statement. ACS and member companies stand ready to assist your efforts to address this important policy issue.

STATEMENT OF THE GEORGIA INSTITUTE OF TECHNOLOGY

HURRICANES ARE GETTING STRONGER, STUDY SAYS

Atlanta (September 15, 2005)—The number of Category 4 and 5 hurricanes worldwide has nearly doubled over the past 35 years, even though the total number of hurricanes has dropped since the 1990s, according to a study by researchers at the Georgia Institute of Technology and the National Center for Atmospheric Research (NCAR). The shift occurred as global sea surface temperatures have increased over the same period. The research will appear in the September 16 issue of the journal Science, published by the AAAS, the science society, the world's largest general scientific organization.

Peter Webster, professor at Georgia Tech's School of Earth and Atmospheric Sciences, along with NCAR's Greg Holland and Tech's Judith Curry and Hai-Ru Chang, studied the number, duration and intensity of hurricanes (also known as typhoons or tropical cyclones) that have occurred worldwide from 1970 to 2004. The study was supported by the National Science Foundation (NSF).

"What we found was rather astonishing," said Webster. "In the 1970's, there was an average of about 10 Category 4 and 5 hurricanes per year globally. Since 1990, the number of Category 4 and 5 hurricanes has almost doubled, averaging 18 per year globally."

Category 4 hurricanes have sustained winds from 131 to 155 miles per hour; Category 5 systems, such as Hurricane Katrina at its peak over the Gulf of Mexico, feature winds of 156 mph or more.

"This long period of sustained intensity change provides an excellent basis for further work to understand and predict the potential responses of tropical cyclones to changing environmental conditions", said NCAR's Holland.

"Category 4 and 5 storms are also making up a larger share of the total number of hurricanes," said Curry, chair of the School of Earth and Atmospheric Sciences at Georgia Tech and co-author of the study. "Category 4 and 5 hurricanes made up about 20 percent of all hurricanes in the 1970's, but over the last decade they account for about 35 percent of these storms."

The largest increases in the number of intense hurricanes occurred in the North Pacific, Southwest Pacific and the North and South Indian Oceans, with slightly smaller increases in the North Atlantic Ocean.

All this is happening as sea-surface temperatures are rising across the globe-anywhere from around one-half to one degree Fahrenheit, depending on the region, for hurricane seasons since the 1970's.

Research suggests that rising sea surface temperatures could mean more storms of the same intensity of Hurricane Katrina.

"Our work is consistent with the concept that there is a relationship between increasing sea surface temperature and hurricane intensity," said Webster. "However, it's not a simple relationship. In fact, it's difficult to explain why the total number of hurricanes and their longevity has decreased during the last decade, when sea surface temperatures have risen the most."

"NCAR is now embarking on a focused series of computer experiments capable of resolving thunderstorms and the details of tropical cyclones," said Holland. "The results will help explain the observed intensity changes and extend them to realistic climate change scenarios."

The only region that is experiencing more hurricanes overall is the North Atlantic, where they have become more numerous and longer-lasting, especially since 1995. The North Atlantic has averaged eight to nine hurricanes per year in the last decade, compared to the six to seven per year before the increase. Category 4 and 5 hurricanes in the North Atlantic have increased at an even faster clip: from 16 in the period of 1975-89 to 25 in the period of 1990-2004, a rise of 56 percent.

A study published in July in the journal Nature came to a similar conclusion. Focusing on North Atlantic and North Pacific hurricanes, Kerry Emanuel (Massachusetts Institute of Technology) found an increase in their duration and power, although it used a different measurement to determine a storm's power.

But whether all of this is due to human-induced global warming is still uncertain, said Webster. "We need a longer data record of hurricane statistics, and we need to understand more about the role hurricanes play in regulating the heat balance and circulation in the atmosphere and oceans."

"Basic physical reasoning and climate model simulations and projections motivated this study," said Jay Fein, director of NSF's climate and large scale dynamics program, which funded the research. "These results will stimulate further research into the complex natural and anthropogenic processes influencing these tropical cyclone trends and characteristics."

Webster is currently attempting to determine the basic role of hurricanes in the climate of the planet. "The thing they do more than anything is cool the oceans by evaporating the water and then redistributing the oceans' tropical heat to higher latitudes," he said.

"But we don't know a lot about how evaporation from the oceans' surface works when the winds get up to around 100 miles per hour, as they do in hurricanes," said Webster, who adds that this physical understanding will be crucial to connecting trends in hurricane intensity to overall climate change.

"If we can understand why the world sees about 85 named storms a year and not, for example, 200 or 25, then we might be able to say that what we're seeing is consistent with what we'd expect in a global warming scenario. Without this understanding, a forecast of the number and intensity of tropical storms in a future warmer world would be merely statistical extrapolation."

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