S. HRG. 105–304

GLOBAL CLIMATE CHANGE

HEARINGS

BEFORE THE

COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS UNITED STATES SENATE

ONE HUNDRED FIFTH CONGRESS

FIRST SESSION

ON

REVIEWING THE EFFECTS OF GREENHOUSE GASES ON GLOBAL WEATHER CONDITIONS AND ASSESSING INTERNATIONAL POLICY OPTIONS TO REDUCE THE NEGATIVE IMPACTS OF CLIMATE CHANGE

JULY 10 AND 17, 1997

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(II)

C O N T E N T S

JULY 17, 1997

INTERNATIONAL POLICY REVIEW

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GLOBAL CLIMATE CHANGE

THURSDAY, JULY 10, 1997

U.S. SENATE,
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS,
Washington, DC.

REVIEW OF THE SCIENCE

The committee met, pursuant to notice, at 9:38 a.m. in room 406, Senate Dirksen Building, Hon. John H. Chafee (chairman of the committee) presiding.

Present: Senators Chafee, Warner, Inhofe, Thomas, Bond, Hutchinson, Allard, Sessions, Baucus, Lautenberg, Reid, Graham, and Wyden.

OPENING STATEMENT OF HON. JOHN H. CHAFEE, U.S. SENATOR FROM THE STATE OF RHODE ISLAND

Senator CHAFEE. We want to welcome everyone this morning. We've got quite a turnout here, so if there are any seats, please take them. If people leave, please do so quietly and the others fill into the seats quietly.

This morning, we will receive testimony on one of the most important and challenging environmental, economic and political matters of our time. That is global climate change. It is a serious issue that requires immediate attention.

To help us better understand some of the fundamental scientific and economic issues which underpin the current policy debate, we've assembled some of the world's leading experts. The full committee will conduct a follow-up hearing 1 week from today on July 17 to receive testimony from the Administration on the upcoming international negotiations over amendments to the 1992 Framework Convention on Climate Change.

The issue of global climate change is certainly politically contentious, both here and abroad. For years now, we've had one side forecasting a scenario of rising seas, recurrent drought, and a blistering heat, all of which they say will result in a ravaged economy.

On the other side are those who claim that meaningful policies to control emissions of greenhouse gases are premature, unwarranted and unfounded and would result in a ravaged economy.

What's going on here? What are the scientists saying? Consider this quotation. "Would it not be possible that the Earth's temperature had decreased during periods of low carbon dioxide and increased when the protective carbon dioxide had been present to a higher degree."

As our distinguished witnesses are aware, this hypothesis was not culled from the text of some suspect environmental organization's manifesto; it was delivered in an 1896 lecture, 101 years ago before the Stockholm Physics Society by the Nobel Prize winning Swedish chemist, Sevante Arenious.

Professor Arenious was the first to predict that large increases in carbon dioxide from humans could result in warming of the globe. What have the world's scientists told us at different intervals over the last 101 years since Professor Arenious first identified the warming effects of carbon dioxide? Here is a sample.

In 1924, U.S. physicists speculated that industrial activity would double atmospheric carbon dioxide within 500 years, roughly 2424. Current projections are for a doubling sometime before 2050, 400 years earlier than predicted 70 years ago.

In 1957, scientists from Scripps reported for the first time that much of the carbon dioxide emitted into the atmosphere is not absorbed by the oceans as some had argued, leaving significant amounts in the atmosphere.

In 1967, the first reliable computer simulation calculated that global average temperatures may increase by more than 4 degrees Fahrenheit when atmospheric carbon dioxide levels are double that of preindustrial times.

In 1985, a conference sponsored by the United Nations, the WMO and the International Council of Scientific Unions forged a consensus of the international community on the issue of climate change.

In 1987, an ice core from the Antarctic analyzed by French and Russian scientists revealed an extremely close correlation between carbon dioxide and temperature going back more than 100,000 years.

In 1990, in an appeal signed by 49 Nobel Prize winners and 700 members of the National Academy of Sciences said, "There's broad agreement within the scientific community that amplification of the Earth's natural greenhouse effect by the buildup of various gases introduced by human activity has the potential to produce dramatic changes in the climate. Only by taking action now can we ensure that future generations will not be put at risk."

In the same year, 747 participants from 116 countries took part in the Second World Climate Conference in Geneva. They reported, "If the increase of greenhouse gas concentrations is not limited, the predicted climate change would place stresses on natural and social systems unprecedented in the past 10,000 years."

In 1992, we had the framework of 153 nations, including the United States, sign the Framework Convention on Climate Change. In that year, they committed the signatory governments to voluntary reduction of greenhouse gases.

The Senate consented to ratification of this landmark environmental treaty on October 7 with a two-thirds majority vote. That was in 1992.

In 1995, the Intergovernmental Panel on Climate Change, representing thousands of climate scientists, concluded "The balance of evidence suggests there's discernible human influence on global climate."

It must be stated that recent IPCC conclusion is based on numerous variables and we're all eager to learn more about these variables and about the certainties from our witnesses. So today we will hear about this evolution of scientific understanding.

I'm convinced the science in this matter has and will continue to evolve. The question is, do we know enough to support legally binding reductions in greenhouse gas emissions as proposed by the United States and numerous other countries? Are we prepared to accept the risks associated with the decision to postpone further action to address potential climate change?

What is being called for? What might be the impacts to our economy? Some say we must stabilize carbon dioxide emissions at 1990 levels by the year 2010. At least one economic model forecast this sort of action would result in economic losses of about 2.4 percent of the GDP. This, of course, is significant.

Others, using more optimistic models, believe that the U.S. economy could withstand significant emissions reductions while prospering as never before. Some 2,500 economists declared in February of this year that cost-effective means are available for the United States to address the threat of climate change.

Let me conclude by identifying what I see as the fundamental questions before us today. First, how much warming might occur as a result of human actions and how soon might such warming occur? What is the range of impacts and when might they be conclusively identified? What do economic modeling and empirical data tell us about the various policy responses?

We look forward with great interest to the witnesses.

Senator Baucus, do you have a statement?

OPENING STATEMENT OF HON. MAX BAUCUS, U.S. SENATOR FROM THE STATE OF MONTANA

Senator BAUCUS. Thank you, Mr. Chairman. I am looking forward to the hearing. We have today scientists and economists who are very imminent in their field.

I was at Rio de Janeiro, as you were, Mr. Chairman, in 1992 and was filled with the expectation and the promise that we're going to finally do something about world environmental problems, including climate change.

Since then, I think the results have been poor, that is actions taken by countries and probably for some good reason. That is, this is not an exact science. That is, we're making lots of guesses here, there's lots of modeling and it's very difficult to know exactly what's happening.

Nevertheless, since 1992, we have a lot more data, we have a lot more studies and we're now in a better position than we were then to know what we should or should not do.

I'm also very pleased that today's hearing is somewhat focused on the science of climate change and also a bit on what some of the actions could be to take to the degree that global climate change is causing quite significant adverse conditions on this planet. That is, we're not yet getting to the policy discussions until next week, but rather, focusing much more on the science today.

I think that's very good and I hope all of us and the panel today do focus on the science because it's important to get the facts before we then proceed to making policy determinations.

Thank you, Mr. Chairman.

Senator CHAFEE. Thank you, Senator.

Senator Thomas.

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

Senator THOMAS. Thank you, Mr. Chairman.

I have a statement I wish to put in the record if I may and just let me say that I think it's very important that we do talk about this as we prepare for the negotiations that will take place both in the next month and then in December.

I happen to be a member of the Energy Committee as well as Foreign Relations, as well as this committee, and we've had hearings of this nature in all three committees. So far, we've focused on the science, we've focused on the policy, but I guess it's important to continue to do that again.

What are the issues? Of course, what should be done; what's the United States' role vis-á-vis other countries; do we put controls on our country and not on others; and what impact does that have? I think those are very important issues.

I am an original cosponsor of Senate Resolution 98 with Senator Byrd calling basically that if we have these binding commitments that they also apply to others. I also hope that those testifying today might give some thought and some consideration to what the EPA regulations that have recently been announced might, in combination, mean as we move on to this.

Thank you, Mr. Chairman. I'll submit my statement.

[The prepared statement of Senator Thomas follows:]

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

Thank you, Mr. Chairman, for taking the time to schedule this hearing to discuss the Clinton Administration's policy on global climate change. As world negotiators prepare for meetings in Bonn later this month, with an eye toward Kyoto, Japan, in December, it is critical that we do all we can to make sure the scientific facts are available and credible. Using good science, rather than emotional rhetoric, ensures we will be spending our limited resources on actual problems.

As some of my colleagues may know, both the Energy and Natural Resources and the Foreign Relations Committees have had hearings on this topic. I am a member of both and, if there is one thing I can report, it's that the science at this point is not "clear and compelling." Furthermore, there is currently no consensus that would compel us to rush into an agreement that will hurt America's economic competitiveness for questionable benefits. Nevertheless, the Administration already seems to have its mind made up by stating that "the science is over."

Before the United States enters into any formal binding agreement, we must first be sure that the effects of global warming are real and the economic consequences are better understood. Unfortunately, the Administration is withholding the fine print details of its proposal from the American people. To the extent that there is a global warming problem, all countries must participate and play by the same rules. If this does not happen, the result is a diminished American economy and a worse worldwide environment. Everyone ought to contribute to the cause. Asking all nations to contribute will help the environment, help U.S. industries stay competitive, and help build new exports as we send our environmental technology and expertise around the globe.

I have repeatedly stated my opposition to legally binding targets and timetables on the U.S. and other developed countries to reduce greenhouse gas emissions, while

at the same time exempting heavy polluters like China, India, Mexico, South Korea and Brazil from those identical requirements. It doesn't take a genius to figure out that they will not have to meet the uncompromising restrictions that will be placed on our industries. Mr. Chairman, by the product of government regulation, we could potentially drive the relatively cleaner U.S. industries out of business, thus increasing emissions of dirtier plants in undeveloped nations. That just doesn't make sense.

I am an original cosponsor of Senate Resolution 98, introduced by Senators Byrd and Hagel, calling on the Clinton Administration not to agree to any measure which would commit the U.S. to a binding international treaty for developed countries, but exclude those standards on China, India, Mexico and others. Although we should constantly work to reduce air pollution around the world, this must be done in a manner that does not threaten jobs or our international competitiveness. I am pleased to report that 62 of my Senate colleagues share this same view and have cosponsored this important initiative.

In closing, Mr. Chairman, we have some expert witnesses and I look forward to their testimony. I would hope that they expand their comments and touch on the Environmental Protection Agency's (EPA) particulate matter and ozone rule which President Clinton recently endorsed. Although 250 Members of Congress, 27 Governors, the U.S. Conference of Mayors and many State and local officials and business leaders alike have expressed disapproval and opposition to the new standards, the president turned a deaf ear. I, for one, believe the impacts of a binding global climate treaty, coupled with the EPA's new air regulations could prove devastating to America's energy-intensive businesses, our Gross Domestic Product (GDP), American jobs and our global environment. Thank you, Mr. Chairman.

Senator CHAFEE. Fine.

Senator Bond.

OPENING STATEMENT OF HON. CHRISTOPHER S. BOND, U.S. SENATOR FROM THE STATE OF MISSOURI

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

I really appreciate your scheduling this hearing today on the science and economics surrounding global climate change. Unfortunately, I have to be on the floor to participate in a debate on a very important amendment that is up, so I'm going to have to read the testimony of these witnesses, but I am very much interested in knowing what it is we know on global climate change. It is my assumption that after this hearing, we may have more questions than answers.

The chairman read some statements from a century ago, and 5 years ago, we saw headlines "As Earth summit nears, consensus still lacking on global warming cause." Six years ago, the Washington Post had articles that we're still trying to find answers.

Yesterday, I read a very interesting piece by Mr. Samuelson in the Washington Post "Dancing Around the Dilemma." He made some interesting points. He said, "The problem with global warming is that we don't yet know whether it represents a genuine national threat, and if so, how large."

"Economic growth requires more energy and fossil fuels provide 85 percent of all energy. Without a breakthrough in alternative energy—nuclear, solar, something—no one knows how to lower emissions adequately without ultimately crushing the world economy."

He ended, "Hardly anyone wants to admit candidly the uncertainties of global warming. It's politically incorrect to question whether this is a serious problem that serious people ought to take seriously." I'm glad we are taking it seriously.

Mr. Chairman, in my position as chairman of the Small Business Committee, I've been hearing for months from small businesses who already have a tough time and have to weave through a mo-

rass of regulations that they are concerned they will face unsustainable costs.

An opinion piece by Karen Kerrigan, President of the Small Business Survival Foundation, addressing the proposed global warming treaty stated, "For America's small businesses, the treaty could be especially harsh. Energy intensive operations, such as bakeries, drycleaners, auto repair shops, small manufacturers and ironically, recycling businesses, would be immediately hit."

Finally, I picked up a book that I have found to be very informative, a book called "Facts, Not Fear, A Parents Guide to Teaching Children about the Environment," which contains information on subjects from endangered species to global warming.

The book points out that back in 1989, "Some scientists were predicting an increase in global temperatures between 3.5—5 degrees Celsius perhaps as early as the middle of the 21st Century.

"In 1990, an intergovernmental panel of scientists projected an increase of 3 degrees Celsius by the year 2100, but the latest estimate is that temperatures may increase by between 1 and 3 degrees Celsius by the year 2100."

Mr. Chairman, some consensus has been reached in the scientific community on some very basic points. First, we do burn large quantities of fossil fuels that add carbon dioxide to the atmosphere which may affect greenhouse gases. Two, the Earth's temperature has increased slightly over the last 100 years.

In my opinion, that's about all the consensus we have. I will be very interested in hearing the chairman's opinion and nobody asked for my opinion, but I'm going to give it to you anyhow. If and when we can develop consensus that global warming really is a problem, then we're going to have to make some tough choices.

Mr. Samuelson said one of the alternatives is to go to something or nuclear power. In this country, we've had hysteria about nuclear power that shut down our nuclear power generating industry. Nuclear fission is something that has engendered a great deal of hostility and fear, but it is not a generator of carbon dioxide, it is not burning fossil fuel and if we want to get serious about global warming, then we have to deal with the realities of nuclear power, nuclear fission in the next 10, 20, or 30 years until we develop the capability of using nuclear fusion energy and that's going to have to be our challenge.

I hope, Mr. Chairman, that we can develop a sound scientific basis for determining whether we are going to get serious about global warming, whether it is a serious trend, and I look forward to reading, though I will not be here to participate in questioning and hearing firsthand the testimony of these distinguished witnesses.

Senator CHAFEE. Thank you, Senator.

Senator Hutchinson.

OPENING STATEMENT OF HON. TIM HUTCHINSON, U.S. SENATOR FROM THE STATE OF ARKANSAS

Senator HUTCHINSON. Thank you, Mr. Chairman.

I would ask that my full statement be entered into the record.

It's interesting when I first came to the Senate, the first hearing that I participated in, the first hearing of this committee was a

hearing on the science dealing with the proposed clean air standards. It's like déjá vu and I really applaud the chairman for looking at the science.

If there's one thing I learned from the clean air hearings, it is that oftentimes scientists are not in agreement as to what the status of true science is regarding any particular subject and I suspect that's what we will be hearing today as well.

I, like Senator Bond, am a cosponsor with over 60 other Senators, of the Byrd Resolution opposing the United States agreeing to any terms in Japan in December that unfairly harms the United States.

If the developed countries alone are responsible for reducing the world's emissions, these nations could face serious economic disadvantages. In Arkansas, where agriculture is the leading industry and is so very important to the economic status of our State and to the livelihood of tens of thousands of Arkansans, we cannot afford to give such a competitive advantage to these developing countries such as China.

We, in Arkansas, are the leading producer of rice—40 percent of the State's rice is exported out of the country. The State's economy relies heavily on rice productions and yet, China produces 24 times the rice of the United States. So if we limit rice production or hinder it in any way, it will not deal effectively with global warming but will put States like Arkansas, and particularly the Mississippi Delta area, which is already an impoverished area, at a tremendous disadvantage and would truly be devastating.

I want to thank the chairman for calling this hearing and for the witnesses who will testify today. I look forward to hearing that testimony and hopefully establishing some factual basis for the decisions that will be made.

Thank you, Mr. Chairman.

[The prepared statement of Senator Hutchinson follows:]

PREPARED STATEMENT OF HON. TIM HUTCHINSON, U.S. SENATOR FROM THE STATE OF ARKANSAS

Thank you, Mr. Chairman.

I appreciate the opportunity to be here today to hear testimony regarding the scientific basis behind the Global Climate. This is kind of a déjá vu experience, because one of my first hearings in the Senate and the first hearing in this committee was a science hearing on the EPA's clean air proposal.

Today we have a similar hearing, this time focusing on the science of the greenhouse effect on the United States. If there is anything I have learned from the Clean Air hearings is that many times scientists do not agree on the science. Despite the fact that it seems to be the common assertion that humans are causing the greenhouse effect, in reality there is some disagreement regarding our actual effect.

There is agreement that humans are adding some greenhouse gases, the disagreement, however is whether these additions are causing significant changes in the Earth's temperature. I have an Associated Press article, that if we have time I might ask the panel to comment on, which states that it is possible that North America's ecological systems have always been in flux.

According to the article, not long ago ice sheets two miles thick covered the entire northern half of the continent. The article goes on to say that as recently as 1850, temperatures were few degrees cooler than they are today and that any warming we may be experiencing now this is merely the continuation of a natural warming trend that began 150 years ago.

These scientific uncertainties are disturbing, especially when considering we are faced with the administration's support for legally binding reductions of greenhouse emissions. Even more frightening, perhaps, than the U.S. being legally bound to re-

ducing emissions, is the prospect that "developing" nations, such as China and Mexico will not be required to implement similar reductions.

I question whether this will do any good at all for the reduction of greenhouse emissions. If humans are causing a great warming of the earth, then all humans must be concerned with this trend, not just the countries that are developed.

This December in Kyoto, Japan, the world will decide what needs to be done to reduce the threat of global warming. I, along with 58 other Senators, cosponsored the Byrd resolution opposing the United State's agreeing to any terms in Kyoto that unfairly harms the United States.

If the developed countries alone are responsible for reducing the world's emissions, these nations could face serious economic disadvantages. In Arkansas, where agriculture is the leading industry, we cannot afford to give such a competitive advantage to these developing countries, such as China.

Arkansas is the leading producer of rice in the United States. Forty percent of the State's rice is exported out of the country. The State's economy relies heavily on rice productions, yet China produces 24 times the rice of the U.S. If we limit rice production, or hinder it in any way, the Mississippi Delta, an already impoverished area would be devastated.

Again, I want to thank the chairman for calling this hearing and for the witnesses who will testify today. I hope we can establish some facts today.

Senator CHAFEE. Thank you.

Senator Wyden.

OPENING STATEMENT OF HON. RON WYDEN, U.S. SENATOR FROM THE STATE OF OREGON

Senator WYDEN. Thank you, Mr. Chairman.

I, too, have a number of meetings this morning but I wanted to come especially today because my State is the first State in the country to legislate mandatory standards for controlling carbon dioxide emissions.

I think the challenge for this committee as we get into this issue is to show that it is possible to lead in this effort to control greenhouse gas emissions without producing an economic meltdown. For real concrete evidence of that, you can just come to our State because what we have shown is that we can make this work, both for the economy and for the environment.

Mr. Chairman, just very briefly, there were really three things that we sought to do in terms of trying to make this system work. The first is we phased in CO_2 emission standards as part of the siting process for new power plants. What happened then was the standards became part of the design criteria for new plants so the developers were actually encouraged to design plants that are more efficient and we reduced the plants' operating costs.

The second thing we focused on was a market-based approach to achieve these standards. We created a bidding process where new energy plant developers compete for plant permits with CO_2 emissions as one of the criteria for awarding the permit.

Finally, we gave credit to developers for creative approaches when they were in a position to mitigate environmental impacts. For example, developers got credits for tree plantings and offset for CO_2 emissions because trees absorb CO_2 from the air, retain the carbon and release oxygen.

Mr. Chairman, I think we all know this is an extraordinarily difficult issue. I've heard several of my colleagues—Senator Hutchinson—make points that I consider extremely important. Certainly we're concerned about the question of what happens when the United States takes a leadership role on these issues.

I would hope that as we tackle this issue in the days ahead, we could look to my home State because I think we have shown a concrete case of how it is possible to control greenhouse gas emissions in a fashion that makes sense for long-term economic growth that our citizens want.

Mr. Chairman, I commend you for your leadership.

Senator CHAFEE. Thank you, Senator.

Senator Allard.

OPENING STATEMENT OF HON. WAYNE ALLARD, U.S. SENATOR FROM THE STATE OF COLORADO

Senator ALLARD. First of all, Mr. Chairman, I'd like to thank you for holding this important hearing and I hope that we can continue to hold these on an annual basis to continue to review the scientific data because I think in order for us to make good policy decisions, it has to be based on good science.

I'm absolutely delighted with the panel that you've brought forward which is going to do the best they know how to present their scientific view of what is happening as far as global warming is concerned. I'm very much interested in hearing what they have to say.

I don't think enough has been said about the buffer system within the whole context of ecosystems in the whole world. I happen to feel that we do have a total buffer system that is very effective.

For example, people talk about the problem of too much CO_2 in the air, but they don't recognize as alluded to by my colleague that trees use CO_2 to kick out oxygen and there is a balance between animal life and plant life. Obviously because of that, there is a large buffer system. Maybe that buffer system is greater in Oregon than it is in Colorado where we don't have so many trees.

I think these are things that have to be thought through. I've been searching the scientific literature for good, solid facts. I'm aware that we are having some information coming down from our satellite systems that indicate there really isn't any real change as far as temperature. In fact, I've seen one report where maybe it's cooled a little bit.

I also realize that there is some modeling out there, and I think we have to be careful with our modeling, about what we put into those models, what we hold as stable fact and what we hold as variable fact.

Again, Mr. Chairman, I'm looking forward to this panel's discussion and the committee's discussion.

Thank you very much.

Senator CHAFEE. Thank you, Senator.

Senator Inhofe.

OPENING STATEMENT OF HON. JAMES M. INHOFE, U.S. SENATOR FROM THE STATE OF OKLAHOMA

Senator INHOFE. Thank you, Mr. Chairman.

Like the rest, I have a statement to be entered into the record. I'll spare you that.

As those who are testifying this morning, I recall that many years ago—in fact, 48 years ago, I was in junior high school and I remember a professor who was absolutely convinced that because

of the global changes that the southwestern two tiers of States in the United States would slide into the ocean and he gave a very persuasive case. By Senator Reid's presence here, we can see that hasn't happened 48 years later.

I'm disappointed in the lack of cooperation that we've had from the Administration. The Administration has not given us information we've requested.

I was with Congressman Tom Bliley from Virginia yesterday and he tells me it's been months now that he's requested information that he has not been able to get.

I've seen some analogous things with what we're going through as has been mentioned by some of my colleagues over here with the ambient air quality standard changes that were proposed by the Administration.

I, as chairman of the committee, had the scientific hearing first and I applaud you for doing the same thing, Mr. Chairman, because I think when we listen to the hysterical things out there such as we went through on ambient air, they first said it was going to result in some 60,000 premature deaths a year, then that was dropped down to 40,000 and after about six hearings, it's down to below 1,000 now.

The Administrator had said initially it was going to cost $6 billion and now, according to the Reason Foundation in California, it's up to somewhere between $90 and $150 billion. So we need to get beyond the hysteria and start looking at the facts.

I, too, am a cosponsor of the Byrd-Hagel Resolution. I feel if we're going to enjoy this, we want everyone else to get in there with us.

I'll be looking forward to this hearing probably more than any others we're having because the science is unclear to me and maybe it will be clearer after this hearing.

[The prepared statement of Senator Inhofe follows:]

PREPARED STATEMENT OF HON. JIM INHOFE, U.S. SENATOR FROM THE STATE OF OKLAHOMA

Thank you Mr. Chairman for calling this hearing today. The debate on global climate change is an important one that deserves considerable attention.

As a cosponsor of the Byrd/Hagel Sense of the Senate Resolution, my position has been clear. I do not support a binding committee for emissions reductions that does not also bind developing nations. In addition, I have serious concerns and questions regarding the underlying science and the economic considerations.

I appreciate Senator Chafee bringing in this panel of experts today to help educate the committee. I am concerned that the Administration has been unwilling and uncooperative in providing the necessary data to Congress regarding the underlying models they are using in their international negotiations. I know Congressman Bliley has been requesting this information for months and his requests have gone unanswered. Therefore we will have to rely upon ourselves to obtain the necessary information.

I know the President has announced that he will convene a White House Conference on Climate Change later this year, but because of the Administration's past record of withholding information and silencing critics, I will be looking at the composition of this panel carefully. I hope the President will ensure that all sides of the debate are treated equally, if the purpose of the panel is to truly uncover the facts.

As the President also pointed out in his remarks, this debate is very similar to the debate on the proposed new standards for ozone and particulate matter. He believes that the new standards are the first step toward addressing the climate change issue. I am concerned that some in the Administration and the EPA are using the ends to justify the means for both climate change and the NAAQS debate.

If the climate change science is as incomplete and uncertain as the particulate matter science, then the Administration is in trouble on this issue.

Because of this, it is my intention to hold Oversight hearings in my Clean Air Subcommittee on the use of the Clean Air Act under this Treaty prior to any Senate vote on Treaty ratification. Again I would like to thank Senator Chafee for calling this hearing today, and I look forward to working with him on this issue in the months to come.

Senator CHAFEE. Thank you, Senator.

Senator Reid.

OPENING STATEMENT OF HON. HARRY REID, U.S. SENATOR FROM THE STATE OF NEVADA

Senator REID. Mr. Chairman, I say to my friend, Senator Inhofe, we, in Nevada, have always been envious of States that have beachfront property.

[Laughter.]

Senator REID. I would also say that I'm sorry that Senator Bond is gone, my friend from the State of Missouri, but I will say to him, and I'm sure the message will be carried by others, that maybe some of those old lead mines in Missouri could be used for nuclear waste disposal if he thinks it's such a good idea.

[Laughter.]

Senator REID. I would ask, Mr. Chairman, that my full statement be made a part of the record.

I'd also say that I'm one of those that appears today to be in a minority on this committee that think we do have problems with global warming. I think it is a problem, I think that the scientific evidence is clear that there are changes in weather patterns that are significant in nature, not the least of which is on our own continent where we've had these storms, these floods that are happening in recent years which just aren't by happenstance. It appears that the same amount of water is coming from the sky; it's just coming in a much shorter period of time.

I think the hurricanes we've had off the coast of Florida are also not just by chance. I think the fact is we know the surface temperature of the ocean only has to raise a very small amount, less than a degree, to cause problems.

I think it's very important, Mr. Chairman, that these hearings take place. I commend and applaud you for approaching this. The hearings are balanced. You have people who have different points of view and our job is to weigh the evidence.

I would say to those who say that the things we do legislatively may not be of significance, we look back 25 years ago when the Clean Water Act was passed and we did that because the Cuyahoga River kept catching fire and the third time, it was decided that we should do something about it.

As a result of that legislation, we've done a remarkable job of making our rivers and streams much better than they used to be. In fact, about 80 percent of the rivers and streams were polluted at the time this Act passed and now, only 20 to 30 percent of them are polluted. So the things we do here have a long-range impact.

I'm confident that this fact-gathering that we're going to be doing here in this committee on global climate change will be significant.

I'm only going to be able to stay through the rest of these brilliant opening statements and miss the meat of the hearing because

we have overlapping jurisdiction hearings that are taking place, but I'm very interested in what is taking place here and I'm going to give it as much attention as I can.

[The prepared statement of Senator Reid follows:]

PREPARED STATEMENT OF HON. HARRY REID, U.S. SENATOR FROM THE STATE OF NEVADA

Good Morning. I want to share a few thoughts on the science and economics of the global climate change debate. Although the committee has wisely chosen to hold one hearing on science and economics, and another on the on-going international treaty negotiations, my comments cannot be so easily separated.

There is a discernible human influence on global climate. Since the dawn of the industrial age, the concentration of carbon dioxide in the atmosphere has risen by 30 percent. Most experts now agree that the buildup of greenhouse gases in the atmosphere due to the combustion of fossil fuels and other human activities is happening. To many this is a troubling phenomenon. Although we are not sure what the exact adverse consequences of this buildup will be, mere common sense dictates that we, at a minimum, begin preparing to deal with it.

The Senate approved the United Nations Framework Convention on Climate Change in 1993, which called for all signatory nations to adopt policies and programs to limit their greenhouse gas emissions on a voluntary basis. The United States had hoped to stabilize emissions in the year 2000 at 1990 levels. Unfortunately, we have fallen well short of that mark.

The United States is, at the moment, the world's biggest consumer of fossil fuels and producer of greenhouse gas emissions. As such, it is important that we must show international leadership in terms of analysis, research, and, if necessary, in reducing these emissions.

As part of the on-going international treaty negotiations, the Administration has moved toward supporting mandatory, legally binding limitations on greenhouse gases for the nations of the World. Within limits, I am supportive of these efforts.

Unfortunately, I share the concern of many of my colleagues that the current negotiations do not seem to require a firm time table for reductions from the nations of the developing world.

The U.S. currently emits more greenhouse gases than developing nations, such as China and India. However, this will not be the case for much longer, especially if the U.S. begins to curb our emissions. While I am not eager to perpetuate the poverty in these nations by mandating that they participate equally and immediately in making reductions, I have economic and competitive concerns about requiring nothing from them.

I cannot, in good faith, ask the citizens of Nevada, who have worked very hard to develop and accommodate environmentally friendly transportation policies and clean industries, to now make more sacrifices without some guarantee that the developing nations will not make similar efforts soon.

In a global economy, we are often forced to compete with other nations that have different labor laws and practices than our own, different rules of resource protection, and yes, often weaker environmental laws. Unfortunately, cheap labor, wasteful resource use, and weak environmental laws often add up to a mighty competitive retail price.

On an issue of such wide-ranging economic impact and consequence, it is unfair to our citizens to let other nations do nothing while we make the necessary sacrifices.

Again, I absolutely acknowledge that the United States must do its part to try to avert any adverse climate change. We are a part of the problem and we will be an important part of the solution.

I would prefer that Senator Byrd's resolution recognize that the nations of the developing world will need some extra time, perhaps as much as 10 years, to put their binding reductions in place.

However, given a choice between sending U.S. negotiators to Kyoto offering unilateral economic disarmament on this subject, and sending them into final negotiations with a stance that demands worldwide equality of treatment now, I must choose to protect the best interests of the United States.

Thank you.

Senator CHAFEE. Thank you, Senator.

Senator Lautenberg.

OPENING STATEMENT OF HON. FRANK R. LAUTENBERG, U.S. SENATOR FROM THE STATE OF NEW JERSEY

Senator LAUTENBERG. I'll be brief, Mr. Chairman.

I want to commend you for holding this hearing because with all of the doubt and with all of the debate, I think that we kind of miss the point. I sense that, as my colleague, Harry Reid said, and nobody caught your joke about the brilliant opening statements and I don't think mine is going to change your mind, but the fact of the matter is we see changes around us that we don't understand. We see changes that are making a huge difference. I've heard reports of rain at the poles. These things aren't just the coincidence of the moment.

We talk about peer reviews and everybody enjoys kicking EPA and some of the agencies around because we disagree with them, but given a task and saying, look, we want peer-reviewed material, and there was a concern that EPA was using less than adequate backup before acting.

However, the critics who demanded peer-reviewed research before we take action seem to have no trouble discounting peer-review research when it suits their purpose.

The tobacco industry comes to mind when we saw evidence, 400,000 people dying each and every year and all kinds of respiratory diseases, suddenly learning that 50,000 fatal heart attacks take place as a result each year of secondary smoke, we had hundreds of thousands of pages of reports galore, the best medical research in the world couldn't convince the industry that cigarettes cause cancer or are addictive.

The plea was, listen, we don't want to put these people out of jobs. No, I don't want to put them out of jobs either, I don't want to prevent the farmers from making a living, but frankly, I must tell you I hear some of the same things being discussed here today.

We really don't know—well, thank goodness, we're going to have a hearing, we're going to have a chance to find out.

Mr. Chairman, I ask unanimous consent that my full statement be inserted in the record and I would like to make one observation because I listened to the Senator from Missouri's references to the Samuelson article.

Through it, he does say that some of this is a gushing source of national hypocrisy at the top. That doesn't mean that he's right and everybody else is wrong. Throughout the article he describes what has to be done politically to make things right even though he doesn't buy into the fact that this thing is really the kind of threat that many of us feel it is.

In his last sentence, he says, "But it would be political suicide to do anything serious about it, so shrewd politicians are learning to dance around the dilemma."

Thank you, Mr. Chairman.

[The prepared statement of Senator Lautenberg follows:]

PREPARED STATEMENT OF HON. FRANK LAUTENBERG, U.S. SENATOR FROM THE STATE OF NEW JERSEY

The EPA, along with other health, environment and safety agencies are under congressional pressure to use good science: peer reviewed research before taking actions to protect the Nation's workers and children. The concern is that EPA was using less-than-adequate backup before acting. However, the critics who demand

peered research before we take action to protect the environment, seem to have no trouble discounting peer reviewed research when it suits their purpose. The tobacco industry comes to mind. Hundreds of thousands of pages of the best medical research in the world can't convince the industry that cigarettes cause cancer or are addictive. At today's hearing, we are talking about global warming. An unprecedented number of scientists around the world, thousands of peer reviewed research and projects all point to the fact that global warming is happening—it is a threat to our environment and we have a moral imperative to act.

A few fringe scientists, generally paid for by industrial polluters, disagree. Essentially, their work is not peer reviewed. However, they are heard because millions of dollars are spent to give these scientists a megaphone that drowns out the undisputed consensus of an overwhelming number of the world's scientists. The threat of humankind changing the climate is real. In New Jersey, we are concerned that global warming will lead to rise in sea level that will devastate our coastal beach resources. As all Americans, we are watchful of extreme weather events and wary of changes in precipitation patterns that could led to floods, droughts and inadequate water for crops.

I look forward to these hearings on what many believe is the most critical environmental issue facing our globe.

Senator CHAFEE. Thank you, Senator.

I want to remind all the Senators that a week from today, namely July 17, we will have an additional hearing and there, the Administration will be present, so I hope everybody will be present for that hearing likewise.

I want to explain to the panel that you may see some of these Senators come and go. As has been mentioned earlier, we have a series of conflicts today with the Thompson hearings and the conference with the House on the tax bill and so forth and the defense bill on the floor.

There are statements from Senators Lieberman and Boxer that I'd like to have put in the record.

[The prepared statements of Senators Lieberman and Boxer follow:]

PREPARED STATEMENT OF HON. JOSEPH I. LIEBERMAN, U.S. SENATOR FROM THE STATE OF CONNECTICUT

Mr. Chairman, thank you for holding these hearings on climate change. I regret that I will be unable to stay for the testimony and questions because this is a very important issue.

Climate change is one of the most serious global issues we face today and in the future. After spending more than 3 years analyzing hundreds of peer-reviewed scientific studies, the Intergovernmental Panel on Climate Change—a group of 2,500 expert scientists representing more than 50 countries—concluded that as a result of human emissions of greenhouse gases, particularly by combustion of fossil fuels, "there is a discernible human influence on the global climate." The IPCC included a diversity of members from individual disciplines who, based on sheer odds alone, are likely to hold widely ranging views within the scientific community. I've been told that getting scientists to agree to anything is as challenging as herding cats. So the fact that consensus has been reached within the IPCC on an emerging scientific issue of such complexity and variety is remarkable, and makes its conclusions very impressive.

The IPCC has tied the increase of atmospheric greenhouse gases to long-term changes in prevailing patterns of temperature and precipitation. Without action to reduce emissions of greenhouse gases, we are likely to see temperature changes in the next 100 years many times those experienced in the last several centuries. The IPCC predicts the number of extreme weather events—floods, heat waves, and droughts—will increase. We know our weather already is becoming increasingly peculiar. In the last few years the frequency and magnitude of floods have been altered dramatically in many regions of the US, along with heat waves, record heat days, severe rains, and dry spells. IPCC experts also predict sea level will rise substantially. The number of citizens in the U.S. living in coastal areas at risk of serious ocean flooding likely will double due to sea level rise. The amount of urbanized

land likely to be vulnerable to extreme weather events is large, raising economic issues of disaster relief, damage repairs, and relocation in many regions.

Changes in climate have major implications for human health, water resources, food supplies, infectious diseases, forests, fisheries, wildlife populations, urban infrastructure, and flood plain and coastal developments in the United States. Although uncertainties remain about where, when, and how much climate might change as a result of human activities, the changes—when they happen—may have severe impacts on many sectors of the U.S. economy and on the environment. These are serious risks that we must start considering.

The fundamental question as we consider a climate agreement is whether the U.S. can develop policies that will achieve significant reductions in greenhouse gas emissions without harming the economy. The news here is promising and suggests that we can afford to meet realistic emissions reductions. First, the National Academy of Sciences concluded in 1991 that "the efficiency of practically every end use of energy can be improved relatively inexpensively . . . and that the United States could reduce or offset its greenhouse gas emissions by between 10 and 40 percent of 1990 levels at low cost or at some net savings." More recently, over 2,500 American economists, including eight Nobel laureates, stated that there are many potential policy options to reduce greenhouse gas emissions for which the total benefits outweigh the total costs. These policies would slow climate change without harming American living standards, and may in fact improve U.S. productivity in the longer run.

We won't find a silver bullet to solve the problem. Luckily, climate change lends itself to flexible solutions. Because it's all one atmosphere, it doesn't matter where or how the reductions are made. It only matters that fewer greenhouse gases are emitted. The 2,500 economists found that the most efficient approach to slowing climate change is through market-based policies such as an international emissions trading agreement. We know from our experience with programs like the acid rain title of the Clean Air Act that emissions trading is very cost-effective because it provides businesses with the maximum flexibility to make choices about how to achieve the necessary reductions.

Given the potential impacts of climate change, it is not surprising that nations of the world agreed to find more effective ways to understand and deal with the problem. If we don't agree to long-term greenhouse gas limits soon, and instead wait to see how our climate changes, it may be too late. Greenhouse gases remain in the atmosphere for decades to centuries, and there is a long lag time between when gases are emitted and when the climate consequences of those emissions appear. So we need to begin reductions soon to have any long-term effect. And, a new generation of energy-efficient technologies requires a long lead time for development and implementation. This won't happen without clear signals to the market.

Recent discussions in the Senate regarding the international agreement have emphasized the role of the developing countries. I concur that this is an important issue, and developing countries ought to make commitments consistent with their historic responsibility for the problem, as well as their current capabilities.

At the same time, I am concerned that elevating one issue to a level of importance that will overshadow other key matters may harm the United States' efforts to ensure that the climate agreement is realistic and achievable. For example, the need for flexibility in implementing a treaty is critical. Some countries, such as members of the European Union, would prefer highly prescriptive policies and measures to meet reduction targets. The United States' negotiating team has made flexibility an absolute prerequisite for any agreement, and I want to commend them for this approach. I believe that to be acceptable, our businesses must have the most flexibility possible to find the least-cost ways to reduce emissions. This means the agreement must contain provisions that are so important to our business community: emissions trading, joint implementation between nations, and appropriate credits for those companies that have already made certain emissions reductions.

As we grapple with the human judgments and values that inevitably will determine how we handle climate change, we must base our actions on the facts—the scientific evidence of climate change, the physical effects that are likely to result from it, and the costs of our "insurance policy" to prevent these changes. Mr. Chairman, I look forward to working with you and the members of the committee as we face these challenges.

PREPARED STATEMENT OF HON. BARBARA BOXER, U.S. SENATOR FROM THE STATE OF CALIFORNIA

Mr. Chairman, today will be the first of two hearings dealing with global climate change, a topic of critical importance to the citizens of our country, and indeed critical importance to all living things on our planet. Global climate change does not recognize State or national boundaries. We are ALL affected by global climate change.

Scientists tell us that human activities since the Industrial Revolution have contributed billions of tons of carbon dioxide into the atmosphere. These activities include the burning of fossil fuels to power our automobiles and industries, as well as certain industrial activities and deforestation. As a result of these emissions, the heat-trapping capability of the Earth's atmosphere has increased significantly, and a majority of scientists agree that there are clear signs of global warming.

The potential changes we will hear about today are alarming. I am very concerned about the potential effects of global climate change because the economy and quality of life of Californians is so closely linked to climate.

EFFECTS ON AGRICULTURE

California is the No. 1 agricultural State in the Union, contributing more than $22 billion per year to our nation's economy while employing more than 1.4 million people. Farmers in my State are concerned that global climate changes will cause highly unpredictable weather and changes in water availability resulting in reduced crop yields.

EFFECTS ON WATER SUPPLIES

Californians depend upon reliable sources of water for their livelihood and quality of life. Warmer temperatures due to increased greenhouse gases could cause more precipitation to fall in the form of rain instead of snow. A reduced snowpack, especially in the Sierra Nevada, could lead to a change in the timing of runoff and potentially greater flooding during the winter and dryer conditions in the summer.

EFFECTS ON HEALTH

Warmer temperatures will likely lead to increased incidents of heat-related mortality and illness, and will have its most disastrous effect on infants and the elderly. Air quality improvements we have realized over the years in California could be severely affected.

Other ramifications include adverse impacts upon forestry, tourism, animal and plant diversity, and ocean shorelines. These impacts are of equal concern for other States.

Finding a solution to this truly global problem will not be easy, nor will it occur overnight. But we must start.

The United States can have a significant impact on reversing global warming.

First, we must listen to the scientific community. The vast majority of scientists agree that global climate change is a reality, and that it is attributable to emissions of greenhouse gases associated with human activities.

Second, we must move swiftly to stabilize and if possible reduce greenhouse gas emissions. The United States has only 4 percent of the world's population, yet we produce more than 20 percent of the greenhouse gases. Measures we take within our country will have dramatic effects on reducing the amount of greenhouse gases worldwide. For example, if we were to raise Corporate Average Fuel Economy standards from 27.5 miles per gallon to 45 miles per gallon we would reduce carbon dioxide emissions by almost 560 million tons per year. Other measures we can take could have similar effects.

Finally, we must develop policies and technologies that will help us meet our global responsibilities and protect our living standards.

I am convinced that there is widespread agreement within the scientific community that global climate change is a reality and a major cause of that change is the emission of greenhouse gases. We need to bring this portion of the debate to a close and for the sake of future generations, focus on *solutions*. We owe those future generations nothing less than our full attention to this critical issue.

Thank you Mr. Chairman.

Senator CHAFEE. I know that Senator Sessions wanted to be here. He is chairing a Judiciary Committee hearing today and particularly, Dr. Christy, he wanted to welcome you here. He spoke to

me about your presence and we're very glad you're here. I know that Senator Sessions regrets that he can't be present.

We will start with Dr. Barron.

Gentlemen, if you will note, here is the green light, then the yellow will come on after 6 minutes and then the red light. So you'll get about 7 minutes apiece.

Go to it and there will be questions for all of you. What we're going to do is have each of you give your statements and then we will have questions from here.

Senator INHOFE. May I ask a question, Mr. Chairman?

Senator CHAFEE. Sure.

Senator INHOFE. I notice we have five witnesses and I think we only received information from four. Was one added at the last moment?

Senator CHAFEE. Dr. Barron's testimony apparently came in late. We'll get it for you.

Dr. Barron, go to it.

STATEMENT OF ERIC BARRON, PROFESSOR, DEPARTMENT OF GEOSCIENCES, AND DIRECTOR, EARTH SYSTEM SCIENCES CENTER, PENNSYLVANIA STATE UNIVERSITY

Dr. BARRON. Mr. Chairman, distinguished Senators, members of the Senate staff and public participants, I believe that the prospect of future human-induced climate change is one of the most complex and serious science and societal issues that we have to face in this century and going into the next century.

We know that humans are altering the environment; we know that they are altering the land surface; we know the composition of our atmosphere has changed. If we look at the very best scientific assessment of these changes, it appears as if the climate response will be something that is large and something that is significant.

At the very same time we say that, we also have to recognize that the air of ours or the uncertainties about those predictions are very large. So really, the major question comes down to the fact of what do you do when the scientific community, and the best scientific assessments we have, suggest that the change is going to be large and that in a sense, we need to look out because the future climate is going to be dramatically different than the present climate.

At the same time, the scientific community is hotly debating the size of the warning label that should be applied to this particular problem.

We have two lines of evidence on which we have to focus. One of them is observations and one of them is the development of predictive models. If we look at the observational record, what we see is that instrumental record is extremely short and at the same time, it was never designed to take the temperature of the planet or the pulse of this earth.

Instead, it was designed to provide weather safety information and weather forecasting information. This means its use in some ways, in terms of climate, has become limited.

At the same time, when we do look at this record, we're beginning to see the signs that the latter half of the century is distinctly

different in terms of precipitation and temperature from the earlier half of the century.

If we go back in the geologic record and look further back over thousands of years, we even see that in some places on the Earth, the record of climate of the 20th Century appears to be unique, but at the same time, if we go even further back in our history on the order of say 10,000 years and 15,000 years, we have to conclude that modern humans have yet to experience the extent of natural variations in climate that we see recorded in that record.

What that means is that we have a ways to go before we can understand the character of this variability and what the distribution of that variability is. We can turn to climate models and look at predictive models and look at what is the best and most comprehensive assessment of what the climate system is like and we also see that there are distinctive limitations.

If we're referring to numbers that are global, what the warming might be within 100 years and we provide that answer within a range, then we tend to see agreement among the scientific community that the warming is likely to occur in that range.

As soon as we move to saying what will happen in a particular decade to a particular region of the Earth for a particular phenomenon, like whether or not we'll experience more intense storms, then we begin to have substantial disagreement and controversy. Unfortunately, at that scale is the very place the climate intersects and interacts with human systems.

We made tremendous progress in the last decade in addressing all of those different issues, but it would be a mistake for any of us to promise you that the solutions to a lot of those issues are going to be addressed rapidly and are just around the corner.

As a matter of fact, I'm willing to bet that in the newspaper articles that we will read 10 years from now, the newspapers will continue to seek out the poles of opinion to put in those papers in order to appear to be giving a balanced view on this particular issue, no matter what the mass of scientific sentiment is on this particular field.

So in the middle of a great deal of public confusion that ends up as a product of this combining the poles of opinion every time you want to discuss this particular topic, we're still stuck with the problem that the models, the records, suggest the Earth is changing and the models suggest some of those changes may be severe.

What should we do? What kind of strategy can we come up with? I think that strategy has to have two elements. One element of that strategy is that we have to maintain a very strong research, observation and modeling program in this country.

It's almost tragic that we have an observational system that we pay for but we don't spend the additional small investment to make sure that observational system can be used to assess climate. It's almost tragic that we have a whole series of satellite observations providing us all sorts of information, but we don't have the continuity of those measurements to ensure that our conclusions from them are going to be robust.

We need to make sure that we work hard to advance on the limitations and high resolution in climate model predictions. We see a number of other countries—Japan and Germany with less robust

economies than we have—right now actively pursuing major observational and modeling efforts. They do this because they realize this advanced information and predictive capability has economic significance.

The second thing is we need some litmus test to be able to decide at what point we should worry about these particular issues. My particular feeling is this litmus test has to be based on the degree to which we're vulnerable or at risk.

If we look around this Nation and take, for example, water resources as an example, if your region, your State is already vulnerable to natural variability, there are droughts and floods, and in addition to that, you see that in these predictions and assessments that there is a continuation of this risk or that risk is even enhanced, then it strikes me since we're already having problems with that water availability, that should be a call for action.

If you look at other areas in which there is potential for significant risk, say for human health issues, so that you see a heat wave brings substantial mortality in major cities like St. Louis, Chicago, Philadelphia or Washington; if you look at the fact that the distribution of mosquitoes that are vectors for disease like dengue fever or malaria, have the potential because of natural variability or climate change to move into more northern States and present the possibility of health risks; if you already have evidence that something like the deadly hanta virus occurred because of natural climate variability in wet-dry cycles or that lyme disease is actually closely tied to how warm winter temperatures are; if you begin to assess these things and realize you have risk for both natural variability and climate change, then I think that becomes a call for action.

The bottom line, basically, of my testimony is that I think we're going to have to live with a certain level of uncertainty. The only way that we can tackle that uncertainty is No. 1, to make sure we have very healthy programs that are addressing these issues; and No. 2, that we begin to make careful assessments of what the vulnerabilities and risks are.

Thank you very much.

Senator CHAFEE. Thank you very much, Dr. Barron.

Dr. Christy.

STATEMENT OF JOHN R. CHRISTY, ASSOCIATE PROFESSOR, DEPARTMENT OF ATMOSPHERIC SCIENCE, UNIVERSITY OF ALABAMA AT HUNTSVILLE

Dr. CHRISTY. Mr. Chairman and members of the committee, I'm honored to be here to provide you with a little bit of information about the climate system.

In the late 1980's, the potential catastrophe of human-induced global warming began receiving a lot of attention, thanks in part to a couple of warm but not recordbreaking summers here in the eastern United States.

The predictions were horrifying—we were going to have rapid temperature rises, coastal flooding, massive hurricanes and so on.

As a student of climate, I and others, were concerned with the lack of proper data to describe the Earth's system and the lack of perspective in which to judge these events as being extreme or not.

In 1989, Dr. Roy Spencer, a NASA scientist with similar concerns, and I set out with an agenda to provide an accurate dataset of truly global observations of atmospheric temperature. These data would not be plagued, as the traditional surface data are, by changing locations or dependence on transient shipping or lack of coverage in very large areas.

We did not know what that dataset would show. Our goal was precision and accuracy, to provide the scientific community with excellent, truly global temperature data.

An added incentive for us, in creating the Microwave Sounding Unit dataset, was that two of the atmospheric layers we were closely examining happened to be two layers which climate models indicated the largest and most rapid responses would occur, if climate change were occurring.

A warming of the troposphere, faster even than the surface, and the cooling of the stratosphere—the troposphere is about the surface to 20,000 feet and the stratosphere is up above 50,000 feet.

Two ways have been used to measure the temperature of the lower atmosphere since 1979, our work, the satellites, and by instruments carried aloft by balloons. I'm a working stiff atmospheric scientist, so I still have transparencies.

This is just a little picture to show you that satellites measure the direct emissions from the atmosphere and balloons carry instruments aloft and they can measure the same layers. Balloons, however, are only released in scattered locations around the Earth where people live and the polar-orbiting satellites see the entire planet every day.

I compared our satellite measurements with those from balloons from 97 stations in the western-northern hemisphere. That was the result, almost essentially perfect agreement.

Senator CHAFEE. I think that will need a little explanation.

Dr. CHRISTY. OK. You see a dotted line and a solid line. One is the balloons and one is the temperature of the satellite system that we have generated for 97 places on the Earth where balloons are located. So it's a satellite looking at the same places where the balloons are, a correlation of .97 trends are almost exactly the same.

Senator BAUCUS. The dotted and the solid lines are the same?

Dr. CHRISTY. Yes, that's what the correlation .97 means.

Senator CHAFEE. The balloons must be at a far lower altitude. What altitude?

Dr. CHRISTY. They go up to the upper stratosphere. They measure exactly the same layer of the atmosphere. The agreement is astounding. These are completely independent ways to measure the troposphere.

So the satellites were providing the precision we had hoped for. Again, I did not, nor did Roy, have any agenda in terms of what the data would show. We were providing a precise record of the atmospheric temperature. This is what we found when we looked for the entire globe. By the way, these are in your verbal remarks, these transparencies.

This is what we found, the troposphere since 1979 has gone up and down but virtually no trend in either direction. The stratosphere has had a significant downward decline in temperature. You can see it is truly affected by volcanic eruptions. Those two red

spikes in the temperature record in the stratosphere are due to volcanic eruptions.

The year-to-year fluctuations due to volcanoes and ocean temperatures affect the top line, the tropospheric temperature. All the ups and downs are not caused by anything with long-term effects; it's mostly the volcano and ocean situation.

So you cannot look at that and really judge if a warming or cooling is taking place because of the length of record. Dr. Richard McNider, a UAH colleague, and I published a paper that calculated and removed the impacts of varying oceanic and volcanic influences to see if a longer-term trend was present.

We looked at that temperature record, calculated the effects from the ocean, which is the second line, calculated the effects from volcanoes which is the two blue impacts there, the fourth line, and the fine result is the fifth line which is the temperature once these oceanic and volcanic effects are removed.

It does show a slight warming trend of .06 degree per decade. It's small enough to be easily placed within the bounds of natural variability, but I can't be certain about that. Humans may be having a slight impact on the global tropospheric temperature. The trend is small.

Senator BAUCUS. You go back how many years?

Dr. CHRISTY. 1979 it begins.

Senator BAUCUS. Thank you.

Dr. CHRISTY. This is a measurement of temperatures from 1979 to 1996, 18 years for the troposphere at the top. These are with balloons and satellites, completely independent comparisons of the tropospheric temperature.

The bottom is the surface record from three different surface datasets. We see the temperatures look like they're going in different directions. The troposphere is pretty steady or slightly downward, we all agree with that. The surface records are upward, roughly around a tenth of a degree per decade.

No climate model I have seen indicates the troposphere should cool while the surface warms for human-induced climate change. With these observations which cover the period of the greatest human impacts on climate, if they are to be evident, that is what we see.

If we had regular weather measurements for the past 5,000 years, we would see centuries in which the temperature rose and when it fell. There would be observations of far more observations of devastating floods, droughts and blizzards more than we have seen in the past 100 years. I'm confident of that.

Focusing on just the 20 years of the satellite record or just 100 years of thermometers doesn't give one a good idea of what has happened in the last 5,000 years or so. If we look at the somewhat murky world of proxy data—tree rings, et cetera—most records do not show this century as remarkably different from the others.

Our present weather woes have always been part of the planet's history, whether it's a drought in the 1930's or the Red River flood in 1997.

I agree with Eric Barron that without a continuing program of observation and research that places climate variations in proper perspective and reports with improving confidence on their causes,

we will be vulnerable to calls for remedies to combat "climate change" because climate change now seems to be blamed for every weather woe that comes along. Such remedies are likely to be unproductive.

The satellite and balloon data, the top line, show that catastrophic warming is not now occurring. The detection of human effects on climate has not been convincingly proven because the variations we have observed are not outside the natural variations of the system.

The stratospheric temperatures which I showed earlier suggest something is going on, but separating the massive effects of the volcanoes is not easily done. If the global atmosphere is our patient, I would say that we've taken its temperature at a few points and there seems to be a slight fever, but we're not sure.

Sensible precautions can be taken. However, my view is that the planet needs a thorough physical to more clearly determine what might be wrong, along with a complete assessment of how effective any medicine would be before it's administered.

Thank you.

Senator CHAFEE. Thank you.

Dr. Lindzen from MIT.

STATEMENT OF RICHARD S. LINDZEN, ALFRED P. SLOANE PROFESSOR OF METEOROLOGY, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Dr. LINDZEN. Thank you, Senator Chafee, members of the committee and staff.

You've heard I think already a certain amount of conflicting information, although what is interesting is the conflict has been larger among the Senators on the committee than the scientists thus far.

I think the reason for that is that 10 years ago when this issue became publicized, it was put forward as simple. The idea was we have gases that absorb heat or infrared, they're increasing, and that will cause the Earth to warm. The gases were known as greenhouse gases.

You perhaps don't understand why such a simple picture has become so complicated and why it's called into question. There are problems with that picture. The Earth's surface does not cool primarily by radiation. It cools by evaporation and convection. The main greenhouse gas is not carbon dioxide; it's water vapor. Water vapor has phenomenal temporal and spacial variability.

We don't even have records that are worth mentioning for water vapor, so we don't even know what's happened to total greenhouse gas. It isn't even a matter of total amount of greenhouse gas. One molecule of water vapor at 10 kilometers has the same effect as 1,000 molecules at the surface.

None of this would be a problem if the models were trustworthy, but satellite measurements of upper tropospheric humidity, some of which have come from Marshall Space Flight Center, Huntsville, are in complete disagreement with models at a level which is profoundly important for climate change.

I'll give you an example later but I might as well mention it now. John Bates at NOAA has analyzed the satellite data and he finds

latitude by latitude models overestimate humidity by about 20 percent. Just for purposes of comparison, 20 percent represents five times the radiative forcing that a doubling of carbon dioxide gives.

In any event, that's a place where we are and you would think that under the circumstances, the situation would be more chaotic than it is. I think, however, there are some areas of agreement and one of them is that I think virtually everyone I know working on climate dynamics agrees that increasing CO_2, carbon dioxide, should have some impact.

The argument is about whether this impact is significant and, in this case, significant has a fairly precise meaning. It's been repeated several times. We're dealing with the climate; it's a naturally variable system. I should point out that means even if you change nothing, it varies.

We've adapted to the natural variability. Significant has to mean that it's bigger than the natural variability. Otherwise, we pretty much know how to adapt to it.

The IPCC, which has been mentioned, came out with a statement that was quoted by Senator Chafee. I think that statement has led to a great many claims by other people than scientists.

The statement is an extraordinarily weak statement. I should tell you of over 20 IPCC reports approximately—I think it's 17 and one is three volumes—since 1990, this is the weakest report. I don't mean weak scientifically but the weakest in its claims.

There hasn't been a progression upward, the numbers go down and down, but let me read the full text of the statement that Senator Chafee quoted.

> Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability and because there are uncertainties in key factors. These include the magnitude and patterns of long-term, natural variability and the time-evolving patterns of forcing volume responses to changes in concentration of greenhouse gases, aerosols and land surface changes. Nevertheless, the balance of evidence suggests there is a discernible human influence on global climate.

What it says, they explain, is that it is unlikely that all of the change in the last century is due to natural variability is simply not true. They make no statement, and they are very explicit on this matter, about the amount of expected change. We said that's what the argument is about. Indeed, except for the peculiar fact that the studies from which the statement is drawn probably are wrong, the statement is nothing to disagree with. Some impact is likely. They're saying it's some. It may be very small, it may not.

As such, it is virtually a trivial statement except that it depends on models replicating natural variability which we know they don't. They don't get major sources of natural variability correct like Enso and El Niño, the quasi-biennial oscillation, etc.

Indeed, a recent study by Polyak and North showed the remarkable fact that models are structurally different from the atmosphere.

The study on which the IPCC study is based is from Santer. It fails the most elementary test of statistical significance, namely the relation doesn't remain when you extend the data record a little. That is the kind of mess we're in: that we have weaker and weaker statements after 10 years of saying it's a self-evident issue and billions of dollars on research expense.

What is perhaps more remarkable from the point of view of policy rather than science are the uses made of this very weak statement. It's a statement which is borderline trivial, says nothing.

Senator CHAFEE. You're referring to the IPCC?

Dr. LINDZEN. Yes, that sentence of discernible influence.

For instance, environmental groups—I just got a mailing from the Union of Concerned Scientists—they do the obvious thing, they start out with that sentence, they change and leave out the front end, as was done here. They say instead, predictions of global climate change are becoming more confident and then they associate it, as I'm afraid Senator Lautenberg did, with everything from heat waves and droughts and forest depletion, forest security and so on, and then conclude we should sign a treaty at Kyoto.

Senator LAUTENBERG. Are you attributing that whole statement you just made to me?

Dr. LINDZEN. No, to the UCS. You only made the one about weather variability. I think Dr. Christy correctly pointed out there has been no discernible change in that. The IPCC certainly hasn't identified any that were predicted.

There are all sorts of statements that lend themselves to misuse. One of my favorites is "many recordbreaking years," Andy Solow and Broadus at Woods Hole showed many years ago, as did someone called Bassett, that it is an inevitable statistical consequence of reaching one record, that you'll have many recordbreaking years following; there is independent information associated with the claim.

Let me finish up, since I'm near the end, with what can we say about increasing carbon dioxide? What can we say it does?

If you just increase carbon dioxide alone, leave out the feedbacks, you'll get something between ⅓ of a degree and one degree for a doubling of CO_2 in equilibrium. This depends crucially on what you mean by holding all other variables constant. That is generally reckoned not to be severe. Everything else depends on feedbacks, of which the largest is the water vapor feedback, which doubles the response and increases the responsiveness to other feedbacks.

The data does not support the ability of models to actually handle that feedback. I think Senator Allard brought up the philosophical issue—I'm not sure if it was he—that in an odd way, it's a philosophical issue. Do we believe that the Earth, when we perturb it, acts to make everything worse or do we believe—I think it was Senator Hutchison who said that—or do we believe that it has some resilience; apparently we're committed to the first view, that the Earth is vindictive.

The last thing I want to say is on policy, namely what would happen if we stabilize emissions at 1990 levels or reduce them a bit because the talk here is climate could be a serious problem and we should do something. Is that doing something?

At MIT at the Center for Global Change Science, what Figure 4 in my testimony tells you is what will happen is determined by the sensitivity of the climate system. We don't know that, but if we assume it's a sensitive system, you'll get a lot of warming with emissions reductions and you'll get almost the same warming, maybe a bit more if you do nothing. If the system is not sensitive, naturally policy won't matter.

So we're not talking about policy to prevent global warming if it's going to occur. We're talking about policy that will have very little impact.

Thank you.

Senator CHAFEE. Thank you.

Dr. Schneider from Stanford.

STATEMENT OF STEPHEN H. SCHNEIDER, PROFESSOR, DEPARTMENT OF BIOLOGICAL SCIENCES, STANFORD UNIVERSITY

Dr. SCHNEIDER. It's an honor and a pleasure to appear again before this committee on the issue of climate change and its potential impacts, particularly since my initial appearance was exactly 20 years ago.

I decided to skim through that testimony because it's often interesting to decide whether you're going to be happy or embarrassed at what you said before.

Several things struck me. First, it was a very cordial exchange among ourselves and the panel and Senators then—Domenici, Wallop, McClure, Gravel and Vincent. If I can indulge in a personal note for a second, it was a pleasure for me to read a transcript where the issues were the primary question, and where the level of contention and personal acrimony was low, as I've been personally distressed in the last 10 years that such a high level of exchange has not always been there.

I'm delighted that the chairman and this committee are beginning to reverse that acrimonious trend by focusing on issues and the questions of science, so I commend you all for that and hope we can continue that style. With that personal indulgence aside, let me continue the debate and contrast what we were talking about then, 20 years ago, to now.

I was struck by how much of the current debate was already anticipated in those days. I think Senator Hutchinson mentioned that this was *déjá vu*. I was thinking of the Yogi Berra cliche about *déjá vu*—one "over again" isn't enough. There are many "over agains" but, on the other hand, that is important when issues have lots of uncertainty and lots of contention. I think it's necessary that each generation go over the issues and see what we've learned in the intervening generations.

I want to briefly address that rather than all the details which are in my written testimony and the other witnesses' as well.

One of the things I had said then, and I'll just quote it briefly and see how it stands up over the test of time:

> There are scientists who believe that the particles, the aerosols, could lead to cooling and to CO_2 to warming.
>
> I personally don't think the issue is resolved, although I think the present majority of climatologists would come out on the long-term warming side.

That was 1977. I don't think it's all that different in a sense that it reflects some of the debate that we would hear now.

Since 1977, we've still learned a lot. One of the things we learned, for example, is that aerosols are implicated not just in climate, but in health risks. They're involved in lung diseases and other things of concern, and as a result of that, we've had a Clean Air Act in an attempt to try to remove the aerosol particles.

What we've discovered is that the control technologies which were originally predicted to be highly expensive turned out to be not nearly as expensive as we thought when we applied market-based systems, such as tradable permits and other such things to them. I think there is an instructive metaphor there.

There is also a climate-related component, which is, if aerosols can be removed quickly when people put health as a high priority. I think that has occurred in more wealthy societies; some of the projections of the amount of aerosols we'll see in the next century may not be nearly as severe as some people have said.

Indeed, as we've been talking about the past 20 years, the prime problem of the next century may very well be if we continue business as usual, then carbon dioxide emissions which start to swamp all the other factors.

So I think there is more confidence today than there was 20 years ago, as the Intergovernmental Panel on Climate Change has stated, that the combination of global warming from greenhouse gases, including not just CO_2 but methane and other greenhouse gases, and a lesser but still significant regional cooling from aerosols, has indeed left its "discernible" mark in that famous sentence that everybody quotes.

Remember, that discernible remark was in the sense of preponderance of evidence, not proof beyond doubt. As one of the lead authors of that report, I know we debated that sentence quite literally for hours. Many of us wanted to use the word "preponderance" to convey that sense of civil rather than criminal trial levels of evidence.

The reason that "preponderance" was not included was that it simply didn't translate well into all the languages of the various countries participating and that's why the "balance of evidence" came out instead.

So it was in that sense that "discernible" appeared. We were not using a statistical standard of 99 percent significance. In fact, that wouldn't be very meaningful because it's hard to define every aspect in those kinds of terms. Climate variation isn't a dice game or a coin flip. There's lots more complexity here.

Let me continue and dwell on this issue of uncertainty because I would argue that it would be a mistake for us to interpret these bland statements about things which are uncertain as if somehow all aspects were equally uncertain.

We have a very ordered set of knowledge here and that is the repeated assessment over every 5 or 7 years that keep coming out from the National Research Council and now several from the IPCC. What they tell us is, there's lots of aspects about the problem that are well understood aspects over which there is a strong consensus. There are aspects for which we have fairly good information and a decent guess and then there are aspects that are highly speculative.

It's always a personal frustration for me when these aspects all get lumped together, particularly in the media debate, as Eric Barron said earlier, and then people become understandably confused and think that nobody knows anything. That's simply not an accurate reflection of the state-of-the-art of the science.

What we try to do is make sure that through the process of assessment where a community of scientists gets together, we can point out those aspects where there is strong consensus and separate these out from the speculations so that we don't misunderstand the nature of the science. That's a tough thing to avoid.

Let me further elaborate on this issue of uncertainty. Of course despite the considerable progress mentioned earlier, there are still many remaining uncertainties. It's the cliche of our era, but as I said, that bland statement by itself throws away much useful knowledge that already exists in the scientific and policy communities.

We know, for example, how to separate those aspects with strong consensus and those parts which are plausible and thus well established and those which are highly speculative, but we can go beyond that because we've actually applied scientific techniques to tap the subjective judgments of a variety of expertise in climatology, atmospheric chemistry, agriculture, ecology or economics.

What such formal studies show is the gradations of uncertainty. What they do is quantify the subjective probability assigned by surveyed experts on such issues as how much the Earth might warm up if CO_2 were to double. I have a figure in my written testimony, Figure 1, which shows examples of 16 different scientists, two on this panel, who have made various estimates of that.

How much the economy might be damaged by different degrees of global warming had also been assessed, as has how much of that damage would accrue to market sectors, areas like agriculture, which is clearly an important market sector, forestry or energy demand as opposed to so-called non-market damages to amenities like visibility, human health or protection of endangered species or habitats.

So anyone who is a "rationalist", meaning we believe in looking at balances between costs and benefits, clearly wants to quantify both the costs and the benefits. Here is where the uncertainty gets in the way because depending upon which end of the spectrum of the range of uncertainties you can pick on both the cost and the benefit side, you can come out with mild or catastrophic conclusions.

So this is no different, in essence, than most risk management problems that corporate executives face all the time or that you face all the time in trying to determine how to use a limited budget in dealing with a wide range of problems, picking which are priorities. Therefore, you want as much quantitative information as you can have, not just about what can happen but also what are the odds that it can happen. By selective information grabbed out of the context of the range of the odds it might happen, it's very difficult for us to be able to do that risk management job rationally.

My written testimony gives several examples of these formal studies and they all possess a common attribute. Most, but not all, experts assign a broad distribution of scientifically-based, subjective probabilities to a range of climatic effects or impacts. In most cases, the vast majority of experts assign a small—5 or 10 percent probability—to outcomes like very little change or catastrophic change.

Of course in the value system of a risk prone person, a 5 percent change of a nasty outcome is small whereas to a risk averse person, that possibility might lead to hedging strategies like investing in insurance or redundant backup systems. Therefore, we need to understand that value aspect all the way through.

Let me conclude with a quote, which I think one of you will recognize, and that succinctly summarizes my views—"If there is one point I could make, Mr. Chairman, it is this. There are a great many questions about the greenhouse effect that can't be answered today, but I don't think we ought to let scientific uncertainty paralyze us from doing anything. It is always convenient to find an excuse not to do something and there is always an excuse out there not to do something. I think the issue before is what steps should we be taking today to help solve the problem in addition to doing more scientific research."

I trust you remember when you said that, Senator Chafee.

Senator CHAFEE. One of the dangers of this job is resurrect things you said in the past, but I'll stick by that.

Dr. SCHNEIDER. Good. That was the gamble I was taking.

Senator CHAFEE. You thought it was a pretty good statement.

Dr. SCHNEIDER. I thought so too and I think it's still true. You said that in June 1988 in front of the Senate Committee on Energy and Natural Resources when, in fact, those heat waves, which were unusual but not extraordinary generated all that public interest to the issue.

I think, as I said, it's as valid today as 9 years ago except today I think we have a stronger consensus for dealing with this issue than we did a decade ago. As the recent statement calling for modest climate policy actions from more than 2,000 economists attests—I will make a bold prediction and that my colleague, Dale Jorgenson's testimony will likewise conclude—that modest actions which try to balance costs and benefits are not premature.

I thank you for your persistent interest in global environmental issues, Mr. Chairman, for inviting me to testify, and of course, I stand ready to respond to any of the questions or comments each of the committee members may have.

Senator CHAFEE. Thank you very much.

Now, Dr. Jorgenson from Harvard, former chairman of the Economics Department and Professor of Economics. We welcome you here.

STATEMENT OF DALE JORGENSON, PROFESSOR OF ECONOMICS, FORMER CHAIR OF ECONOMICS DEPARTMENT, HARVARD UNIVERSITY

Dr. JORGENSON. Thank you very much, Mr. Chairman.

Distinguished members of the committee, it's a great pleasure for me to be here and to see the breadth of interest in the subject that we're here to discuss.

I think it's very important for me to focus right away on the fact that I'm going to deal with the economics of climate change and not with the scientific issues that the other four witnesses have just placed before you.

I was the author of the Economists' Statement on climate change that attracted, as the chairman said, more than 2,500 signatures,

including eight Nobel Prize winners. I'd like to use that as a point of departure. That's in the material I distributed. It's about halfway through the packet. I'm going to start by summarizing the statement because it's an attempt to elicit what turned out to be close to a consensus about an economic approach to the problem.

First of all, let me say a few things about the economics of the situation somewhat in the vein of Senator Chafee's opening remarks about the science.

The science of global change is at least a century old. It was originated, as the Senator pointed out, by Svante Arrenhius and the qualitative features of the science of the problem haven't changed even though the quantitative precision, thanks to the excellent observations that you've heard about from Dr. Christy and the modeling which Steve Schneider, among others, has been involved in, we know a great deal more about the quantitative features, but the qualitative features of climate change go back at least a century.

The economics is much more recent and in fact, for the benefit of the panel and also for the benefit of the staff and maybe some of the members of the audience, I've included a few recent references which are research reports that I think have moved the economics forward by a good bit.

It turns out that these are very recent references. One of them is to a World Bank report from June 1992. It was intended to be available at the same time as the Rio Summit, but in fact, arrived just as the Summit was beginning and therefore, had no influence on the outcome.

The other references are to a book by William Nordhaus of Yale University. I know, Senator, you are an alumnus of that very distinguished university. William Nordhaus is a co-author of the Economists' Statement as well as one of the leading economists working in this area. Finally, there is a paper by myself and Peter Wilcoxen, a former student of mine now at the University of Texas, which is dated 1995.

Notice that all of these references are subsequent to the Rio conference. In other words, what we know about the economics of climate change is something that has arrived on the scene very recently. I think it's very appropriate to underline that by referring to the article that appeared yesterday in the Washington Post—if your copy of the Washington Post has already disappeared, you can find this also in Newsweek Magazine, by Robert Samuelson, surely one of the most distinguished economic journalists working in the area of economic policy.

The phrase that he used is precisely the opposite of the economic consensus. The phrase, which you quoted, I believe, Senator Chafee, was that "Effective action on climate change would amount to crushing the world economy." That turns out to be exactly the opposite of what I believe the economic consensus appears to be.

It reflects a view of the economics of this problem which I think goes back to the reactions to the Rio Summit and to the definition of the problem that was adopted there which, unfortunately, as I've already suggested, did not benefit from the recent economic research that I want to discuss.

Let's proceed with the Economists' Statement. That is about midway through your packet if you'd like to refer to it but I'm going to summarize it very briefly.

The first paragraph says that climate change involves significant environmental risks and the preventive steps are justified. The second paragraph summarizes economic studies showing that there are policies available for educing greenhouse gas emissions for which the benefits outweigh the costs. The third paragraph describes policies in more detail and emphasizes the importance of the approach you've heard from a number of the other panelists and also from some of the opening statements, many of which I found to be brilliant—I hope Senator Lautenberg agrees.

These opening statements, a number of them, refer to market-based approaches and that is, in fact, something that is gaining a good bit of momentum in this area of environmental policy and in others. That is the basic thrust of the Economists' Statement.

Now, I'd like to lay out the approaches to practical implementation. Again, this is on page 5 of your handout if you'd like to look at that.

The first thing we have to focus on is how to choose an appropriate objective. It's very clear from the testimony that you've heard that there is certainly the possibility that emissions of greenhouse gases will affect the climate.

Senator CHAFEE. Doctor, could you slow up here? I'm just trying to get located. You said page 5 in the handout material?

Dr. JORGENSON. Right.

Senator CHAFEE. Is that the big print?

Dr. JORGENSON. Yes. This is the big print and talks about practical implementation.

Senator CHAFEE. Yes, all right.

Dr. JORGENSON. That's exactly the page, Senator.

The first point is that we have to agree on an appropriate target. That is something that was discussed at the Rio Summit but in fact, the target that was suggested there, which is stabilizing emissions, is not something that can be justified on economic grounds. That is the first and most important point.

When we think about setting the target, the Rio agreement is the wrong starting point and we'll come back to the setting of the target later.

The second point is we have to think of a means of international implementation. This is where we come to the issue of market-based approaches. I'm happy to say that the Administration, which you will hear from at the next meeting of this committee, has proposed a market-based approach based on internationally tradable permits.

That has important limitations, some of which are the subject of the Senate resolution by Senator Byrd and others, including members of this panel, but that is something we can discuss in more detail.

Now we come to the issue of domestic implementation. Here, the issue is how to achieve reductions in emissions that balance the costs against the benefits. The answer to that, and this is discussed in great detail in my paper with Wilcoxen, is that we need to think about a carbon tax, we need to think about a tax on energy use

that would have the effect of reducing the growth of carbon dioxide emissions, not the most important greenhouse gas to be sure, but the one for which atmospheric concentrations are changing.

Now we come to Mr. Samuelson. Mr. Samuelson says, thinking we're going to crush the world economy, that to have an appropriate effect, the appropriate carbon tax would be $100 per ton of carbon. The appropriate tax discussed in my testimony is, in fact, $10 a ton. In fact, that $10 figure is for the year 2025. If we wanted to think about an appropriate tax at present, what would be the tax that we should implement immediately, the answer is about $5.29 a ton, in other words, a totally different order of magnitude than what has been suggested.

The conclusion is then that we have to think of this as a three-step process. The first is determining an appropriate target for an international agreement. Unfortunately, the Rio Summit of 1992 got off on the wrong foot. What is required is slowing the growth of emissions, not capping emissions at something like 1990 levels.

The second point is that once we've agreed, hopefully in Kyoto, but if not, then at some subsequent meeting, on an appropriate target that is justified in terms of the costs and the benefits that are associated with slowing climate change, we then have to arrive at a means of international implementation.

For that purpose, I think the Administration's position involving a system of internationally tradable permits is certainly an appropriate point of departure, but it's important to combine that with the key feature that has been the subject of the Byrd resolution which is bringing in all the parties, in other words having an international agreement that is truly comprehensive.

Now we come to the nub of the matter. We have a climate change policy. It is, in fact, embodied in the U.S. Climate Change Action Plan. If you look at the final exhibit in my handout, you'll see the effect of the Climate Change Action Plan.

There was an objective of trying to achieve by voluntary methods a reduction in emissions by the year 2000 to 1990 levels. That was what was called for in the Rio Summit. That has been, unfortunately, a total failure.

What we have found is that the emissions have grown very, very substantially. Even by 1996, the last year for which the most recent data are available, these have grown far beyond what the Administration at that time—Senator Chafee alluded to the Senate ratification of the Administration agreement by President Bush at Rio—that there would be a growth of emissions without this Global Climate Action plan that would go far beyond stabilizing emissions. In fact, the growth of emissions has been far beyond what was anticipated at the time.

Nonetheless, we come back to the basic point that the goal of climate change has to be reconsidered and that economics is really the key to understanding that issue.

Thank you very much.

Senator CHAFEE. Thank you very much, Doctor.

What we will do is each of us will have 8 minutes to ask some questions. I understand there is going to be a vote at 11:05 a.m., so I'd like to start off. Sometimes votes are scheduled and don't occur.

Dr. Barron, if I understood your testimony correctly, you stated as a fact that there has been a global temperature increase. Am I correct in that?

Dr. BARRON. If you look at the surface observations over the entire century, what you see is the differences that are on the order of .4 to .6 of a degree Celsius. I don't think anybody argues that over that span of time, that there isn't some temperature difference.

Senator CHAFEE. You indicated that there must be a strong research and observational system and apparently we don't match the Germans and the Japanese in that. What are they doing that we're not doing? We had the testimony from Dr. Christy about the balloons and the satellites.

Dr. BARRON. I think what you're seeing is just somewhat of a change in attitude where if you look at our satellite observation programs, they are under continual challenge, year to year in terms of budget, in terms of scope, to the point where we once again are moving into a mode where it will be difficult to make sure we have continuity of our observations.

This was something where basically the United States just ruled supreme in terms of these observations. Now we're seeing that the Europeans and the Japanese are putting forth very strong efforts along those lines.

If you look at the IPCC assessment, you see the unusual circumstance that it is models from other countries providing the long-term simulations that were the basis of a significant portion of that report and I think much less participation on the U.S. side.

There's a lot of different U.S. activities and a lot of very healthy U.S. activities, but I just think it's important to make sure that we continue to maintain those.

Senator CHAFEE. How do the Japanese make these observations? They don't have satellites up there to the extent we do.

Dr. BARRON. Yes, they do. Unfortunately, they just lost one, Addios, which just went dead because of some sort of power failure and they have plans for the next launches of Addios and we did have a U.S. instrument on board that satellite, a wind-scatterometer.

Senator CHAFEE. Do you believe the global temperature has increased due to an abundance of CO_2 from the Earth?

Dr. BARRON. I think there is a distinct probability that a component of that warming is due to CO_2, but I also believe we have a very strong natural variability segment in there that we have to address.

If you'll let me go back a little farther in Earth history, I would tell you that every single time there was a warm time period, there is evidence of higher CO_2 and of almost all the cold periods we have, there's evidence of reduced CO_2.

It's not that it is the primary cause in every single case, but if we look through the entire spectrum of Earth history, warm time periods have higher CO_2, cool periods have lower CO_2, and it's very hard to escape that point.

Senator CHAFEE. How would we get the variations in CO_2 emissions say going back before the Industrial Revolution? Would it be from volcanic eruptions or something?

Dr. BARRON. We have several sources of information. One is an ice course.

Senator CHAFEE. I appreciate that. That would be a way of measuring it, but what would the variations come from? What would cause pre-Industrial Revolution variations in CO_2?

Dr. BARRON. It's probably a whole broad range of factors. On a very long time scale, it has to be the volcanic emissions and the rate of uptake of that CO_2 by actually weathering of rocks, but you have all sorts of variations from variations in the biology, variations in the climate for which it becomes a feedback. It's a broad range of factors.

Senator CHAFEE. Dr. Christy, you indicated in your conclusion that something is going on but you're not sure what. What is the something? You reported since 1979, there's been a very small increase in the temperature in the troposphere. Is that the something?

Dr. CHRISTY. No, it was the stratosphere that had the largest signal, the remarkable decrease. The cause could be due to ozone depletion, that seems to be a good culprit for that, or the effects of volcanoes which is quite a natural phenomena.

Senator CHAFEE. If you were sitting up here, what would you do? Would you worry and do anything or say, well, let's wait a little while longer?

Dr. CHRISTY. I've never been a Senator before.

Senator CHAFEE. You can pretend you're one, a lot of people do. [Laughter.]

Dr. CHRISTY. I suppose whatever could be done, that which is politically feasible, from your point of view.

Senator CHAFEE. No, don't put it on that basis. Let's say we're trying to do the right thing up here. Long before it was popular, we got into the chlorofluorocarbons, the CFCs, and as you just mentioned, I think we did some good work there. It wasn't immediately popular, but it was the right thing to do. Just tell us what your recommendation would be to us.

Dr. CHRISTY. To find out as much as possible, first of all, about what the climate is doing and what effects a particular control might have. The modest controls talked about here and probably to be recommended will probably not have much effect on the global climate, if it is being affected by the greenhouse gases.

I'm not an expert on the economic issues and things like that. I only know about pretty much one thing and that's the satellite temperatures, so it's hard for me to answer that kind of question.

Senator CHAFEE. Except that your satellite temperatures, as I understood them, indicate some small increases in temperature. Am I correct in that?

Dr. CHRISTY. When adjusted for the natural variations of the ocean temperature volcanoes, that's right, less than what model projections show.

Senator CHAFEE. Dr. Schneider, you indicated that it's unfair to label all uncertainties as being equally uncertain. How certain are you that there's been an increase in the global temperature?

Dr. SCHNEIDER. I'm highly certain that there's been an increase in the global surface temperature. I'm less certain about what the middle of the atmosphere is doing and I'm more concerned about

what happens to the surface because that's where we and the bulk of living things are.

Senator CHAFEE. Could you put a figure on that?

Dr. SCHNEIDER. Remember, these probabilities are subjective because there are many factors involved but so are the opinions often of generals, doctors and others, so my subjective opinion on this would be 95 percent likely that there is a global warming trend, probably even higher than that because it isn't just thermometers of the world which average out to show this 1 degree Fahrenheit warming in a century, but mountain glaciers have been largely receding around the world and sea levels have risen. There is a consistent pattern.

The issue isn't so much whether the Earth is warming, it's why.

Senator CHAFEE. It's also important how much, isn't it?

Dr. SCHNEIDER. Yes.

Senator CHAFEE. Could you set a figure on that, how much?

Dr. SCHNEIDER. How much is a little tougher even at the surface because you can't just stick a thermometer in somewhere and get out the number. That's why many of us are pleased that the satellite measurements have come along to provide a supplement, yet there is a lot more adjusting that needs to take place in coordinating the instruments.

Unfortunately, satellites were only flying in 1979, so we have to try to guess about where there were inaccuracies and so forth.

I think what the IPCC said and the National Research Council said before, is that the standard best guess is something like a half degree warming over the past century, plus or minus a couple tenths of a degree, and there are four groups around the world that continuously reanalyze this data to try to take out biases and correct errors.

Senator CHAFEE. Senator Baucus.

Senator BAUCUS. I'd like to see if there is any agreement among the panel first as to whether or not there's been an increase in CO_2 caused by man over the last 100 years? Does everybody agree there has been a significant increase in CO_2 caused not by natural causes, but by man?

The figure I have is that 250 ppm to about 360 ppm over the last 100 years.

Dr. LINDZEN. It's closer to 280 ppm.

Senator BAUCUS. The range is from 280 ppm to——

Dr. LINDZEN. To 360 ppm.

Senator BAUCUS. OK. The primary causes of that are what, fossil fuels?

Dr. SCHNEIDER. Fossil fuels and deforestation. The initial deforestation was in the now-developed countries. If we had a balloon and we could have flown from the East to the West Coast of the United States before the settlers were here, we largely would have seen trees more so than farms and that carbon that those trees then represented is now in the air. The same thing is true in Europe.

Now we've been regrowing our forests and the bulk of the net deforestation is taking place elsewhere.

Senator BAUCUS. So there is agreement that CO_2 caused by man is increasing?

Dr. SCHNEIDER. More than half is probably from CO_2 due to industrial emission.

Senator BAUCUS. More than half due to industrial.

Is there also agreement that the surface is warming, has over the last 150 years? I'm not getting into the cause but whether the surface has been warming?

Dr. LINDZEN. I think the IPCC limit is ⅓ to ⅔ of a degree. There is uncertainty in that. While there is widespread agreement, for instance, it's been mentioned that there's urbanization, I had to work with these records a few months ago and I suddenly realized the IPCC listed Capetown, Johannesburg, and Buenos Aires as rural stations.

Senator BAUCUS. But there is general agreement?

Dr. SCHNEIDER. There's general agreement, it's got a large error bar and nobody knows why.

Dr. JORGENSON. Let me chime in at this point. if you look at Figure 5.4 of my testimony, you can see what appears to be the consensus about global mean temperature changing from 1865. It's increased by a little over a degree (Farenheit).

Senator BAUCUS. The next question I want to ask you scientists is to rate the probability of individual causes. The cause of today's hearing basically is CO_2 and other greenhouse gases. Dr. Lindzen, you say water vapors is much more.

Before we get into that, I just want to ask each of the panelists to give his view of what's caused this warming, two or three candidates and the best you can give a probability to each of the two or three candidates.

I'll start with you, Dr. Barron, and answer very quickly because I don't have a lot of time left.

Dr. BARRON. I think there's a significant probability that a good portion of that has to do with human activity.

Senator BAUCUS. With what?

Dr. BARRON. With human activity.

Senator BAUCUS. Which human activity?

Dr. BARRON. Emissions of CO_2.

Senator BAUCUS. Emissions of CO_2. You think there is a significant probability?

Dr. BARRON. I think there's a significant probability.

Senator BAUCUS. OK. Dr. Lindzen.

Dr. LINDZEN. I would say at this point, the most likely candidate is natural variability. As I point out, this is the system that vacillates with no forcing, even according to models and theory.

Senator BAUCUS. Dr. Schneider.

Dr. SCHNEIDER. If you consider the surface warming together with the cooling of the stratosphere, which actually I think is due not just to depletion of ozone but increased greenhouse gases, they actually cause the stratosphere to cool and the lower atmosphere to warm, I would say that it is maybe only a 10 or 20 percent change, in my opinion, that the warming trend is a natural event.

There is an equal probability it could have been a cooling event in nature. I don't know which it is, so I would rate it more like 80 or 90 percent likely that we're part of the story and that the bulk of that is probably emission of carbon dioxide.

Senator BAUCUS. Dr. Jorgenson.

Dr. JORGENSON. I'll defer to Dr. Christy.

Dr. CHRISTY. I look at those records very closely and the 19th Century was one of the coldest of the last 1,000 years. We are coming out of a very cold century right now. Most of the temperature rise—and I sat on the IPCC panel that dealt with this—the number was .42 was given to us by the latest results of a degree Celsius warming.

Most of that is caused by natural variability, the rebound from the 19th Century cold period. What part of that might be caused by our activities of the .42, I would say at most, .1.

Senator BAUCUS. Caused by man?

Dr. CHRISTY. Human activity.

Senator BAUCUS. Point 1. Did you say there's a 10 percent change?

Dr. CHRISTY. No. I would say at most that warming of .42 that we see, at most, .1 would be due to human cause, at most.

Senator BAUCUS. What lessons are there from the CFC matter? Years ago, it was a big debate, were CFCs causing a hole in the ozone layer in the stratosphere? Lots of industries said, no, but we went ahead and worldwide enacted controls.

I'm just wondering if the state of knowledge here is in any way parallel or similar to the state of knowledge back when we first started to debate this issue? Does anybody want to take a crack at that? Dr. Schneider?

Dr. SCHNEIDER. Sure. In fact, one of the prime confusions in the lay world is that the ozone depletion issue and the greenhouse effect question are the same. In fact, they are not. They are very different but there is a component of them where I think we can draw a lesson as you asked in your question.

When you use the atmosphere as a free sewer, if you will, eventually something nasty might happen. It was determined that those chemicals that were injected could be breaking down and while nobody could precisely calculate the chemistry 15 years ago, there was a possibility it could be significant. It became a risk management question about whether to take the chance.

Now, the ozone hole that you mentioned, the irony in this and the chief lesson, is the ozone hole was not anticipated by most people. In fact, what we were expecting was a smooth, slow loss of ozone. The ozone hole came as a surprise, which was interpreted by some people who didn't see this as a problem. They were saying, "You see, we never really understood the atmosphere because we didn't predict the hole." On the other hand, it was interpreted by environmentalists and others as, "See, when you mess around with Mother Nature at the global scale, you're going to get nasty surprises."

I think that it's almost certain that the rates at which we modify the environment, both through land clearing and atmospheric effects, will give us surprises. Some will be pleasant, some will be nasty. The absolute prime message is that when you start interfering with the natural rates of things, you have to expect changes, as Eric Barron said.

What we are not capable of doing is honestly telling you the precise range and details of those changes. If we did, we'd be beyond our capacity. But we can forecast that the more rapidly we force

the system to change, the more likely it is that there will be surprises like the ozone hole. I think that's a relatively safe forecast.

Senator BAUCUS. I'd like to follow up very briefly on the question the chairman asked, namely how do we go about getting more data, either baseline data, more research, more facts so that we can be a little more certain that our decisions are better founded than they otherwise might be? Where is the deficiency in either research or data gathering? What do we do?

Obviously this is a big problem—global warming, climate change—and I think intuitively most people think something bad is going on here, but we also want to make sure, as much as possible, that we handle it the right way and make the right decisions.

It seems to me that the best way to address that is, as you all suggested one way or another, to get more data, do more research and so forth. I don't know what it is. What do we do to make sure we're getting better information, more facts? Any of you?

Dr. BARRON. I'd just add that I think there are some things like, for instance, making sure when you're collecting weather data that it's suitable for climate. A few simple rules and policies and a little bit of investment would go a long way.

I think it's clear just by the debate where deficiencies are in models.

Senator BAUCUS. If we could spend more money, where should we spend?

Dr. JORGENSON. Could I check in on that? I think the thing to focus on, Senator Baucus, is that we are spending $2 billion a year on this problem. It's not as if our efforts are insignificant in economic terms. We're putting a lot of money into research and we're getting the benefits of that research as you see before this panel.

I don't think it's a question of spending more money. It's a question of absorbing the information that we have and maintaining, as Dr. Barron suggested earlier, the observational system that we've put up, making sure it continues.

Senator BAUCUS. But I understand that Japan, Germany, and other countries are doing more.

Dr. JORGENSON. That's simply not true. If you look at our effort by comparison with these other countries, it's very large by comparison with our R&D effort and by comparison with the size and scope of our economic activities. We are the leaders in this field by a substantial margin.

Senator BAUCUS. Thank you.

Senator CHAFEE. Thank you.

We're in the last part of the vote. This is what I'd like to do. We'll take a little recess now and we'll go over and I think a lot of us want to hear these answers and we'll come right back.

This is interesting to all of us. Why don't we all go and vote and I personally am going to come back very quickly and then we'll start again. I hope everybody will be here because we're all interested in what you have to say.

Thank you.

[Recess.]

Senator CHAFEE. In our order of appearance, we had Senator Thomas who is not here, Senator Bond is not here.

Senator Hutchinson.

Senator HUTCHINSON. Thank you, Mr. Chairman.

I want to thank the panel for their testimony and as I listened, it seemed to me one word kept popping up and that's the word "uncertainty," that there was at least some uncertainty regarding the scientific data that we have.

I think, Dr. Christy, the one thing that almost got lost when you were playing Senator, was when you said that we need to gather more data. There did seem to be a lot of uncertainty to me.

I read an AP article not long ago that quoted a U.S. Geological Survey ecologist who said he was uneasy about attributing ecological changes to human-caused global warming because North America's ecological systems have always been in flux.

A mere 18,000 years ago, not long in geological time, ice sheets two miles thick covered the entire northern half of the continent and as they melted away, plants and animals claimed the land the glaciers once covered.

He says there have been smaller climate fluctuations since then as recently as 1850 at the end of a period known as the Little Ice Age when temperatures were a few degrees cooler than they are today and that leaves ecologists wondering whether the changes they are now documenting are merely the continuation of a natural warming trend that began 150 years ago.

I think it was Dr. Lindzen who questioned the models, the accuracy of the models that are available, so I think of the scientific uncertainty.

As I listened to the testimony, it also struck me that there is uncertainty as to the impact of policy changes that have suggested as to how dramatic a change we can really affect by making the policy changes that have been proposed, particularly the ones that have been proposed by the Administration.

So we have, at best, a marginal impact. In fact, I think I'm quoting Dr. Lindzen correctly when he said they would have very little impact.

When you consider that the proposals that we have before us, the Administration's proposals would limit the regulations to developed countries, excluding and exempting the developing nations like China and Mexico. It would seem to me that they would even further marginalize the impact of any policy changes.

So in the midst of all that uncertainty, it seems to me there is one thing that is certain and that is there is going to be enormous costs that's going to be imposed. While we are uncertain about the scientific basis and that we need more data, we're uncertain about the impact of policy changes, that it may or may not be beneficial, but there is one thing that is quite certain and that is, it is going to be expensive.

Dr. Lindzen, I'm going to direct this to you and I know you're anxious to speak but I want to particularly look at the area of agriculture. Agricultural production accounts for 20 percent of all human-caused greenhouse emissions according to the Intergovernmental Panel on Climate Change.

In their study, they further singled out rice as the No. 1 agricultural source of human-caused methane emissions, 20 percent of all human-causes from agriculture and rice being the No. 1 contributor

of that. Arkansas is the No. 1 rice producer and the Mississippi Delta is the place that's grown.

Current negotiations only focusing upon developed nations will put Arkansas and other areas at a great disadvantage. In fact, in 1996, the United States produced 7,771 metric tons of rice while China produced 188,000 metric tons of rice, 24 times the amount the United States produces.

It seems to me if we're going to regulate, we're going to limit American agriculture, which would be about 4 percent of world production of rice, any impact is going to have to be very, very minimal.

Here is the question. Is the proposal the Administration has advocated the proper response in light of the uncertainty that surrounds the issue?

Dr. Lindzen.

Dr. LINDZEN. I think the issue of uncertainty has to be dealt with with care. There are some things we're uncertain about to be sure, but on the issue you asked about, surprisingly there is rather less uncertainty than on many matters.

We know, for example, that projected increases in methane will contribute very little of any putative warming, no matter what you think will happen; CO_2 will dominate.

We know that stabilization of emissions involving India and China at 1990 levels will, if you expect 4 degrees warming, doing nothing much, knock you down to maybe 3 degrees.

We know that the No. 4 is very uncertain but we know if that were the number, the proposed actions will not reduce it to a number that would be small climate change.

Senator HUTCHINSON. You're saying the certainty is that the policy changes would have minimal impact?

Dr. LINDZEN. That's the part we're far more confident of than the specific number we expect to be achieved in 2100, if we do nothing.

Senator HUTCHINSON. Dr. Jorgenson.

Dr. JORGENSON. I'd like to expand on that. I think that what you said, Senator, whatever we do is going to be very costly is precisely the point of view that was expressed by Robert Samuelson in his Washington Post piece.

That is predicated on the idea that we're going to continue our failed policy of 1992. That's the policy that involves stabilizing emissions at 1990 levels by the year 2000. That is not economically justified.

If you look at the figure in my testimony, Figure 5.2, what you'll find is that the economic—this is at the end of the handout and it's Figure 5.2 and describes greenhouse gas emissions under the optimal economic policy.

Senator CHAFEE. This is a chart?

Dr. JORGENSON. That's a chart. What this shows is that the optimum policy is one that does not stabilize emissions. That scenario would indeed, Senator Hutchinson, be extremely costly, and that's what Dr. Lindzen was alluding to.

Senator HUTCHINSON. That would be ineffective also.

Dr. JORGENSON. Not that it would be something that would be effective in stopping climate change; but the point is it is not economically justified.

Weigh the costs against the benefits—as you have with your example based on rice culture in Arkansas—but I think is appropriate. Farming is the industry that is going to be most affected by this policy. Whatever we do, we need to think about very moderate measures.

Instead of Samuelson's $100 tax, what we need to think of by the year 2025 is something like a $10 tax per ton of carbon. That's a difference of order of magnitude. That is where the economics of this boils down to. We need to take very moderate measures, but we need to start now.

As far as the developing countries are concerned, the important thing to focus on there is that at the present time, developing countries are not going to be very substantial emitters. However, we can anticipate the growth of emissions from countries like China is going to be substantial. Therefore, we need to bring them into the discussion.

Senator HUTCHINSON. Dr. Jorgenson, if China produces 24 times the rice that the United States produces and if it is only a modest tax as you're advocating that would be imposed, even a small differential between a developed nation like the United States and China which is producing 24 times, it's hard for me to imagine that's not going to have a dramatic impact in markets and costs on American agriculture.

It also seems to me to argue that China is not a significant emitter if it's producing 24 times the rice. That doesn't equate with me.

Dr. JORGENSON. No, at the present time, China certainly is a significant emitter. My point is that if you take developing countries as a whole, they are far less significant than the developed countries.

Focusing on the role of China, China, like the United States, will have opportunities to participate in an international agreement. They will benefit from looking at the costs on the one side and the benefits on the other and what we should try to achieve is an international consensus based on the idea that we minimize the cost of whatever we do. We want to minimize the cost of climate policy, whatever that policy turns out to be.

For that purpose, I think the Administration's proposal of internationally tradable permits, when expanded in due course, to the developing countries, would be an appropriate market-based instrument.

Senator HUTCHINSON. Mr. Chairman, I know my time has expired but Dr. Schneider was wanting to respond and I would like to ask permission.

Senator CHAFEE. Go ahead.

Dr. SCHNEIDER. I just wanted to clarify something. In the charts that Dale Jorgenson showed with economic justification for certain actions, including figures with three and four decimal places of precision, although I agree in principle with what he's trying to say, I have to remind us that these are based upon economic models which assume what cost profiles will be because they assume what the cost of technology will be. They also assume what the damages to the economic system will be from various levels of climate change.

There is a wide range of uncertainty on both of those factors. One of the things we learned after the OPEC price rises, which were induced by political action, was that the economy responded to those price rises through inventing much more efficient technologies. We now have the indelible benefits of the improved technology because of the inventive genius we had once we had an incentive.

One of the hopes of those people who call for modest solutions like a low carbon tax, for example, is not that it will, under present assumptions, eliminate the climate problem, but will help to induce the kind of learning by doing and technological changes that can make it much, much cheaper to abate carbon in the future and that those steps need to begin now in order to get that process going.

I would commend the idea of what he said, not the three decimal place precision. It's not conceivable that we could have that kind of precision, given that we don't know yet what our technology would be.

Just in your State, think about rice as you mentioned. You're already in a warm summer state and therefore, the question isn't just what the cost is of the rice emissions, it's also what is the damage to the rice farmers if you increase the numbers of a certain kind of heat waves. That's what we call climate damage.

What we're trying to do in these optimizations is balance a guess of how the world would be damaged by climate change against a guess of what the costs would be to the economy of say, increasing the price of energy.

That leaves out the whole range of surprises like the ozone hole and other factors, so it could very well be cost effective to have much more control than is on this chart if we were unlucky and it turned out the damages were higher than the best guess.

Senator HUTCHINSON. I'd like to agree completely with everything Mr. Schneider just said.

Senator CHAFEE. Excellent.

Senator Allard.

Senator ALLARD. Thank you, Mr. Chairman.

I'd like to direct a couple or three questions to Dr. Barron.

Dr. Barron, according to the 1995 IPCC report, there has been some pretty substantial strides differentiating greenhouse gases released naturally and greenhouse gases caused by humans. Do you agree with that?

Dr. BARRON. Do I agree with the precise numbers?

Senator ALLARD. No. Do you agree there has been substantial advancement scientifically in being able to measure greenhouse gases caused by natural causes as opposed to human origin?

Dr. BARRON. I think that makes sense.

Senator ALLARD. Could you detail for me the amount of greenhouse gases you would attribute to human sources as opposed to natural sources?

Dr. BARRON. I don't think in some precise number, it's a number that I know what it is. Sorry. I work more on the climate modeling side of things and less on the biologic-chemical flux side of this.

Senator ALLARD. Do you know whether or not there's been an attempt by the committee or anybody to break down these emissions

by country so that we would know the impact of the Annex I countries, for example, versus developing countries?

Dr. BARRON. There are all kinds of assessments that go country by country.

Senator ALLARD. Did the IPCC try and break those down and you do have some conclusions on that. OK. I'll want to run down those conclusions and review those.

The 1995 report seemed to modify greatly certain predictions that were made earlier, particularly if we look at the 1990 report. The 1995 report estimates for an increase in global mean surface air temperature one-third lower than those estimated in the 1990 report.

The 1995 report indicated that sea level changes are 25 percent lower than estimated in 1990. Many of you had indicated that there was considerable modification. If that's the case, why shouldn't we maintain a good case of skepticism on the 1995 report? What's changed?

Dr. BARRON. I think you should maintain a level of skepticism and I think several people have mentioned this uncertainty issue. Of course you've got to realize we're trained basically almost at birth as prenatal scientists to question everything and to focus on all the uncertainties of every particular issue. It doesn't really release us from responsibility on some of the decisionmaking.

Part of the progress that you will make over a period of time between those assessments is that in some cases, you're going to see that a focal point like aerosols and aerosol effect on clouds wasn't as clearly recognized and for which over 5 years, people began to look at that particular factor may cause the estimates to be smaller or extend the time scale of the warming.

You also see that there are time periods that the advanced knowledge adds a level of uncertainty. We're just beginning to realize that vegetation, if it changes with the climate that's projected, is going to contribute to the climate change in itself. It isn't just something that's passive.

So these things become initially areas of uncertainty and as progress goes on, then we begin to add higher levels of uncertainty. To tell you the truth, if I look back over the broad history of this problem, the things we've had questions about, we've had questions about for about 20–25 years because it takes a long time to solve some of these things.

The broad picture of the warming is not dramatically different.

Senator ALLARD. You bring up the balance of the plants and the interaction. I'm trying to think in my own mind. If we assumed on the plant side we had adequate nutrients and we increase water or water vapor, we increase humidity and we increase temperature, I would expect plants to grow more, bigger, faster and I would expect the by-product from that would be more oxygen.

I'm not sure there is enough discussion. In my comments, I talked about the buffer part of the system. I don't think there's enough discussion about that.

Dr. BARRON. That is an issue that is really just beginning to come on line in terms of how high latitude plants will respond because we've gone from the point of looking at the atmosphere with

trying to couple all these different components of the system. I know that's going to introduce uncertainty.

There are some areas that also build a little bit of confidence that you know the climate system is sensitive and you know these models can't be too far wrong in some ways. I'll just give you one example.

We're now at the point where there have been literally hundreds of experiments in trying to predict past planets because we can predict the present day but that's how we built the model. You predict the future, you don't know whether you're right or wrong.

You can go back in the past and try to predict the last Ice Age or the last warming episode. In the hundreds that have been done with models all over the world, there is not a single case of a model overpredicting the climate of the past, cold or warm.

Senator BAUCUS. What do you mean by overpredicting?

Dr. BARRON. That means that the geologic record says it was cold and you used one of these climate models and it said it was colder than what it actually was or you use one of these climate models to predict a time period that was warm and it actually made it warmer than it actually was in the past.

Senator BAUCUS. So they didn't overpredict?

Dr. BARRON. In every single case, it underpredicts. There's a lot we don't know.

Senator BAUCUS. Underpredict cold and warm?

Dr. BARRON. Underpredict cold and warm. There's a lot we don't know about the climate system, there's a lot we don't know about that data, but it begins to be suspicious when you look at every single time period and you discover you underpredict.

One other example, you can take that same range, severe storms leave a remarkable record in sediment, ripping up sediment stones. You can take different continental positions, different CO_2 levels that geologists think occurred and almost every storm deposit that we have that's been recorded in the geologic record comes up under the model predicted storm tracks.

I would say there's something about the characteristics of those simulations that must be fairly robust. There's a lot of things in there I wouldn't trust at all. I think you can come up with this ordered list, but I think there's evidence that we have a sensitive system on our hands.

Senator ALLARD. If I have time, I do have a question for you, Dr. Schneider, but go ahead and respond.

Dr. SCHNEIDER. Briefly, I was going to clarify that the comment you made before about how early reports suggested warmings on the order of five degrees as the top number, then that went down to three and the sea levels come down. There is an important clarification and distinction I wanted to make.

There was no difference from the first report to the second report of the IPCC or, in fact, over the last several reports of the National Research Council, on the basic sensitivity of the climate to a given change in carbon dioxide. That's not what changed.

What changed was the assumption of what human behavior would be, how much sulfate aerosols would be generated, for example, and the assumption that was made in the 1995 report was that China would have uncontrolled coal burning that would produce

lots of sulfate aerosols that would offset some of the global warming.

Now the current assumptions are that they will not allow that on health grounds and therefore, those combined global warming numbers will probably, in the next assessment, creep right back up. It was the difference in the assumptions as to what people will do, not a difference in the sensitivity of the models that caused the change in projections.

Senator ALLARD. I've been called to order by the chairman, but hopefully we can come back and maybe continue some of this discussion later.

Senator CHAFEE. Senator Inhofe.

Senator INHOFE. Thank you, Mr. Chairman. I'm going to cut mine down to only 4 minutes because I'm running out of time. If you can keep your answers short, I'd appreciate it.

Dr. Barron, I didn't see your testimony before the meeting, but you said we maintain a sophisticated observation system. We have the satellite but not the continuity. I don't know what you mean by "not the continuity."

Dr. BARRON. You can take, for instance, the MSU records. There's a paper that just appeared in *Nature* which basically looks at other techniques and thought there was an issue about the trends because it's not a single satellite.

I have a great deal of faith that John Christy knows that data inside and out, but here it becomes a matter of some debate because it's multiple satellites. Now we've set about in this Nation to create an earth-observing system with which we can address issues like that and make sure that we can begin to have this long-term record.

That system has gone through a tremendous amount of debate and we don't want to launch the same thing over again. We've finally come down to the point where we're going to launch a couple of these satellites. We've got about 9 months to decide on what the next set of satellites are like and we're not ready.

Senator INHOFE. Dr. Christy, do you have any response to that?

Dr. CHRISTY. Just that, yes, we used nine satellites to piece the record together but as I showed by the independent validation, it was done correctly.

Senator INHOFE. Dr. Barron, you are predicating a lot of these predictions on the computer models and I think last April there was an article in the Washington Post, if you can help me through this, where the National Weather Service was trying to predict the cresting of the river in North Dakota. In a 2-week period, they went from 49 feet to 50 feet to 52.5 and 54 and so forth.

I guess the question I would ask is aren't there more variables in predicting, as in your discussion, than there would be in something like this? When you talk about a timeframe of 2 weeks, wouldn't the incidence of accuracy be damaged a little by looking at 100 years versus 2 weeks?

Dr. BARRON. It's true, except you also have to realize that weather prediction is quite different than climate prediction. In weather prediction, you're basically starting at an initial stage which is observed and you're carrying that forward based on laws

of physics into the future and you're updating it with the new observations as you go along.

What that means is the error grows the farther you go into the future and so that's basically weather prediction. To predict something 2 weeks in advance is a very challenging issue.

In climate prediction, you're basically looking at a set of factors that forced the system to change and you're attempting to see what is in equilibrium or balance with those particular forcing factors. It has a completely different set of problems and errors. We don't want to just accept what it says, it has a completely different set but the two issues are quite distinct.

Senator INHOFE. Dr. Jorgenson, I have a quote from your book. You submitted kind of an outline as opposed to the test of your remarks, so one of my staff read your book, "The Economic Effect of Carbon Tax." It says, "Stabilizing the atmosphere and concentration of carbon dioxide which would lead to an eventual stabilization of temperature would require reducing emissions by 50 percent relative to 1990, a very costly policy."

My question would be, a minute ago you said we're not talking about capping, we're talking about reducing the growth. When I read this, my interpretation was capping. Was my interpretation wrong?

Dr. JORGENSON. What I did in that paper was to look at the consequences of various policies. I considered stabilizing the climate, which is what you're referring to; I considered stabilizing emissions, which is the objective of the Rio Summit Agreement; and what I put in my written testimony and in the outline you referred to is the economist's best policy defined by the one that produces the most benefits relative to the cost.

That doesn't involve capping the climate or capping emissions. What it involves is reducing the growth of emissions very, very modestly. That means that the climate is going to continue to change and that we're going to have to learn to adapt to that.

Senator INHOFE. But the treaty that we're going to be looking at is talking about capping, isn't it?

Dr. JORGENSON. I think that it's to be determined because at the moment, there are a number of proposals on the table. The small island states needless to say, a relatively insignificant group from the political point of view, is talking about reducing emissions by 20 percent. The Europeans—they don't agree on this, in particular the British don't agree with this—have talked about reducing emissions by 15 percent.

The goal that is to be advocated by our Administration in the Kyoto meetings and the meetings that lead up to it is to be determined. They don't actually say what the goal is. What I'm saying is it is up to you to determine that. That is what I suggest you do. I've laid out what I believe that should be, namely a very, very modest reduction.

Senator INHOFE. I am out of time. I have one last question I'd like to ask. I know scientists cannot answer questions yes or no, but I'm going to ask you to do that or not answer it at all, starting with Dr. Barron.

It's a yes or no question. You mentioned, Dr. Barron, in your testimony that the models have limitations causing uncertainties. The

Administration is moving forward with a treaty which will be finalized in December. Will we have these uncertainties answered by December, starting with you?

Dr. BARRON. Absolutely not.

Dr. LINDZEN. No.

Dr. SCHNEIDER. No.

Dr. JORGENSON. No.

Senator INHOFE. I do have other questions I'll submit in writing.

Senator CHAFEE. Dr. Jorgenson, as I understand what you're advocating is that we don't try and stabilize our emissions at some year, but that we seek, I believe you used the term modest reductions. Those I think you were seeking to achieve by what, 2023, or something like that?

Dr. JORGENSON. No. This would be a continuous process. I'd like to begin as soon as possible and continue indefinitely. This is not a problem that's going to go away.

Senator CHAFEE. The trouble is we have to have incentives to make us take that tact, that approach, limitations of some type. In other words, some witness said when the oil embargo came, the country responded and came up with alternatives and lowered fuel consumption. Yes, that's absolutely true but there was a driving force; the driving force was the oil embargo.

We had the reduction in CFCs because we mandated them pursuant to the Montreal protocol and so forth.

Therefore, it seems to me that in order to get these, we've got to have some mandate to force us in that direction. This is not easy. Let me just give you a tiny illustration.

Because of the Social Security Fund problems in 1983, we enacted some social security reforms and indeed, increased the retirement age from 65 to 67, being gradually phased in starting at the turn of the century and extending up to 2023.

Also, many of us voted to make the Medicare age correspond with that. You think that's pretty gentle, 2023. Nobody can get too excited about that, but it doesn't turn out that way. There is a lot of resistance to that. The House of Representatives, I think will see that as this conference goes along.

Just because something is in the out years doesn't necessarily make it much easier to achieve. It should work out that way, but we've got to have a driving force. What are you suggesting be that driving force?

Dr. JORGENSON. Senator, the driving force I think in environmental policy is always the same, namely it's the damages. These damages sometimes take the form of health effects, as in the case of the Clean Air Act, we've talked about sanitation associated with clean water standards, cleaning up the Cuyahoga River and things like that.

In this case, we now have a substantial amount of economic evidence and it's based on the following idea. That is that changing the climate with all the uncertainties that have been described by this panel is something that is going to have a negative, not gigantic, but a negative effect on agriculture. It's going to have a negative effect on forestry, it's going to have a negative effect on our requirements for energy, for heating and cooling. It's going to have a negative effect on the coastal areas.

It's easy to exaggerate that but nonetheless, we will be confronted by coastal damage which will require efforts at mitigation that involve building dikes and the sort of thing that has been done in the Netherlands for centuries. All of those things add up to about the equivalent of a whole year of economic growth over the next century. That is not the most dramatic problem you're ever going to confront in the environmental arena, but it is nonetheless a very substantial amount of damage.

That is the motivating force for the concern of scientists, economists and others. How do we mitigate that damage? The answer is that we do it very gradually. It's not something that is dramatic and overwhelming. It's something that requires modest but nonetheless substantial measures. That's what I've tried to place before you.

I'd like to make one qualification. That is the emphasis in this panel, both in terms of the questions that the panelists have asked and the responses that you've heard from the scientists is uncertainty. That is an argument in favor of action, not an argument in favor of inaction.

That leads to the recommendation that now is the time when we need to think about these things as you and your fellow panelists have decided to do. I think that's the driving force. It's the damages to our economy, the damages to our ecology, the damages to our environment that will result from global warming with the uncertainties that we've heard about.

Senator CHAFEE. Let me ask the panelists. You heard Dr. Jorgenson recite the potential problems as he sees them. Do you agree those problems exist—shall exist.

Dr. BARRON. I think that if you start to make a list and you go sector by sector. If you start to do that, then I think there is a lot of reason to be concerned.

Senator CHAFEE. What do you say?

Dr. LINDZEN. Yes, I'm very perplexed by Dale's remarks. If the emission caps and emission reductions will lead to very little mitigation of climate, then your more relaxed approaches would have an unmeasurable effect on climate. So if they have a benefit, it must be something unrelated to climate. What is the benefit?

Dr. JORGENSON. I'm sorry. Maybe I didn't make myself clear. The policies that I've advocated are precisely those that reduce the damages and do it at minimum cost. That's the economist's approach.

Dr. LINDZEN. What damages with respect to climate do they minimize?

Dr. JORGENSON. The measures that I proposed are measures that involve reducing emissions and thereby gradually reducing the change in the climate. That's something that will have benefits for farming, benefits for forestry.

Dr. LINDZEN. Excuse me, Dale. You keep saying that but what you're proposing by emissions reductions, rate of increase will have almost no impact on climate.

Dr. JORGENSON. It will have a very modest impact on climate. I emphasized in my presentation, I hope, that the climate will continue to change. We not only need to mitigate the change in the way I've suggested, we need to adapt to the change that's going to

take place, which is your point. Therefore, I think we're in agreement unless I misunderstood you.

Dr. LINDZEN. No, no. I just didn't understand what the point was at all in reducing the emissions vis-á-vis climate.

Dr. JORGENSON. Not to eliminate climate change. I certainly didn't mean to suggest that there's any way that is economically attractive of putting climate change at an end. That is not the objective of the policy that I'm advocating.

What we need to do is to mitigate that change, to slow the change, but the climate, as you've emphasized, will go on changing.

Senator CHAFEE. I think you left him perplexed. You've got me semi-perplexed. Now that I understand what you're saying, I'm not sure I agree with you.

What you're saying is the climate is going to change because of man's actions.

Dr. LINDZEN. No. He's saying if it changes, any policy will not impact that. If it isn't changing——

Dr. JORGENSON. That's not right. Why don't you try, Senator.

Senator CHAFEE. Doctor, you can mark my blue book.

Dr. JORGENSON. I've never marked the blue book of a Yale man. [Laughter.]

Senator CHAFEE. What you're saying is that man's actions are causing climate change. It will have, as we go into the next century, significant effects on agriculture, forestry, the oceans and so forth.

By starting now with modest mitigation efforts, namely reducing some of the CO_2 that we're releasing into the atmosphere, we will reduce the effects. We're not going to eliminate them, but we will reduce the effects and presumably by reducing these effects, we will be able to adjust to these effects as we go along.

Dr. JORGENSON. If you don't mind my marking that blue book as A-plus. You got it exactly right.

Senator CHAFEE. I'll take it and move on.

Senator Baucus.

Senator BAUCUS. I'd just like to follow up. Frankly, I think we're in a real dilemma here because if the efforts are modest—$10 a ton by 2025, whatever—I don't know if that's going to have a significant reduction on emissions.

At least now the economy is doing OK. As I see the utility vehicles that people buy and the gas guzzlers, they buy big cars and so on, I just don't know if that level is going to have a significant effect at all which gets a little bit into the other side of the coin. Sometimes we just need a shock to force changes in peoples' actions, to develop new technologies and so forth. The oil shock did it. Sputnik sure did. We woke up and saw Sputnik flying around and that galvanized us into action.

Generally it's my judgment politically nothing really happens unless either there is a crisis or there is extraordinary leadership. I don't see a lot of the latter.

Dr. JORGENSON. I think although it's invisible, we've had serious efforts inside the Administration to formulate a climate policy that would meet the objectives that I think all of you are concerned about. I think you're going to hear more of that. There is a lot of concern politically out there in the population about climate issues.

I think the focus needs to be the following. If we look at the impact of the oil crisis—I think it's important to come back to that—we had the benefit there of experience, namely that increases in prices, just increases in prices by themselves had the effect of stabilizing emissions.

Senator BAUCUS. Dramatic increases in prices.

Dr. JORGENSON. Dramatic increases in prices, stabilizing emissions from 1973, the beginning of the oil crisis until 1987. That's the longest period in recent history for which we've been able to stabilize emissions. So we know how to achieve the goals of climate policy.

Now we come to the question Senator Chafee addressed which is, what should those goals be. There, I think we don't need to be dramatic. We need to say there is a need which I think you've heard testimony on this morning and you're going to hear more testimony on.

Senator INHOFE. I understand that but I think there's a dilemma here. I don't think it's going to shock people into change frankly and change behavior. I just don't know that.

Another question I have is with respect to other countries. You mentioned developing countries don't produce much. An exception is China.

Dr. JORGENSON. Right.

Senator INHOFE. I heard someone mention not too long ago that if there is about 3 billion more tons of carbon produced in the world in the next 20 years and one-third of it will be produced in China because of their power plants primarily. That's significant.

Dr. JORGENSON. That is significant, Senator, but let's just focus on China. China is a country which has undergone a lot of economic reform and it's been very successful in producing economic growth.

The one thing they have left untouched is their market for energy. They have continued to maintain energy prices well below world levels. Think, by contrast, with the countries of the former Soviet Union and Eastern Europe, which are also very energy intensive. Those economies have reduced their emissions dramatically as a result of moving their energy prices to world levels. That is essentially the policy that we need to think about for China, not something that involves endorsing an international agreement. We need to get them to focus on reforming part of their economy which is the energy sector. We need them to move their energy prices, especially the price for electricity to which you alluded, to world market levels.

What does that mean in practice? That means that they will need fewer power plants than they otherwise would need. It means they're going to make efforts to reduce their reliance on coal. You can already see them moving in other directions just by what they know about the forces that will be at work in the future.

They have not taken the critical step and that's where we can play a role. Namely, they have not decontrolled energy prices in the Chinese economy, so they have not had the kind of dramatic reductions in energy use that we've seen in the former Soviet Union, another ex-communist country or in the countries of Eastern Europe.

I think there is an opportunity to do something about China entirely outside the framework of the kind of international agreement that will be debated at Kyoto. That should be the goal of our diplomats specifically Under Secretary Wirth, the Under Secretary of State in charge of global affairs. I hope he's going to focus on that in Kyoto.

Senator INHOFE. Is El Niño at all relevant to anything we're talking about here today?

Dr. LINDZEN. Can I answer that a little bit?

Senator INHOFE. Yes.

Dr. LINDZEN. There have been a number of studies while Wallace, Zhang and others at the University of Washington and elsewhere. These are leading scholars on El Niño, looking at the changes in El Niño and trying to decide whether they have produced the changes of temperature in the 1970's or whether it goes the reverse.

By and large, changing patterns associated with Enso seem to have played a major role according to Wallace's papers in the temperature change observed in the 1970's. This is part of the autonomous variability of the system.

Dr. BARRON. But that begs the question of why El Niño changed.

Dr. LINDZEN. That's all right but you take the view that all changes occur because something forced them.

Dr. BARRON. No, I wasn't. I was just saying there wasn't an answer to a question there.

Senator BAUCUS. Dr. Schneider.

Dr. SCHNEIDER. First of all, El Niño is a natural phenomena and has been for a long time, although there have been some very unusual El Niños in terms of prolonged ones and some very intense ones, which has naturally raised the question, "Gee, it happened at the same time the climate was changing. Maybe these are not independent events."

The answer is we haven't got a clue what the answer is. This could be another one of those imaginable surprises. It's simply one of the risks we take when we modify the system. We do not know if they are connected or disconnected—yet.

However, one thing we do know from El Niño is that social and economic systems still remain vulnerable to extremes of climate and weather. We can quantify how those rapid changes can lead to significant impacts in terms of droughts, floods and so forth.

That lesson tells us that we're vulnerable to natural variability. But are we vulnerable to unnatural variability? The answer is probably yes, but if we had some advanced warning—that's where the research comes in—and if we knew exactly what would be happening, we'd be more able to adapt than otherwise.

The question is how can you reduce the most rapid rates of change which, I would argue, would be more likely to cause unpredictable extreme variability than slower rates of change.

Senator BAUCUS. What's your reaction to Dr. Jorgenson's comments?

Dr. SCHNEIDER. I'm glad you asked but the red light kept coming on so I kept not having them.

I was going to call your attention to a figure I had in my written testimony, Figure 3, which Bill Nordhaus prepared. He was frus-

trated when he was trying to do exactly the same thing many years ago as a pioneer of this kind of work—to try to balance in an optimizing framework, the mitigation costs and damages due to climate.

What you want to reduce first is the cost of abatement, trying to mitigate CO_2 by increasing the price of energy, which might hurt the economy. He was attacked from all sides because he picked 1 percent loss of GDP for his climate damage function.

He was attacked by environmentalists because this value underestimated, in their opinions, damage to nature and it neglected health effects. He was attacked by others for the point about resilience, that his 1 percent GDP damage estimate neglected CO_2 fertilization effects—which could be benefits.

So he asked a number of people, about 18 or 19 people—I was one of them—and he conducted a survey and said what do you believe climate change damages would be? We recognize you can't calculate it precisely, but you study the fields, so give your best guesses.

In my testimony Figure 3 shows the two different scenarios of change, 3 and 6 degrees, and what he found is that the economists as a group tended to have lower climate damage estimates but they were not negligible. They would assign a 10 percent chance of a benefit. Their 50th percentile estimate was about half of a percent loss of GDP and then their 10th percentile radical number on the high side was several percent loss of GDP. So again, it's a risk question. They viewed climate damage across a wide range.

When Nordhaus asked the natural scientists, they gave a factor of 20 higher in their estimates of climate damages, to which Bill quipped that, "those who know the most about the economy aren't so worried." I counter-quipped, "those who know the most about nature are."

Part of the difference is that the natural scientists were less optimistic about the resilience of nature than the economists. But you can't know for certain. We're not going to have the uncertainties resolved in time either. The sword of uncertainty has two edges and one edge is we might be lucky and things will come down. The other edge is we might not be so lucky and it's back to risk management again.

To me, the best way to manage risk is to have flexible management, because in a state of large uncertainty, you don't want to make irreversible decisions. You don't want to make irreversible decisions that damage the economy, nor do you want to make irreversible decisions that damage the ecology.

My support for Dale Jorgenson's call for a modest tax is not because I think that over the long term, I want to see only a small percentage of climate change be mitigated, but I'd like to get the experiment started of finding out how that tax would induce technological change, how the prices of alternatives would come down so there isn't an economic catastrophe from a big change being needed later on.

If we don't start that process now, we'll be building power plants which have 40-year life times that will emit a lot.

Senator BAUCUS. Thank you.

Senator CHAFEE. Senator Sessions.

Senator SESSIONS. Thank you, Mr. Chairman.

It's a fascinating subject and I'm not going to ask a lot of questions. I'm sorry I was unable to be here. I consider this a most important hearing but I did have markup on a juvenile justice bill on a committee I chair and it was important for me.

Dr. Christy, first, I want to welcome you here. I'm delighted that the chairman could invite you. I've read about some of your work and have not had the chance to meet you.

I know you are funded by NASA and have done extensive work. In some respects, it shows that parts of the atmosphere have actually cooled in the last number of years, is that correct?

Dr. CHRISTY. Yes. We're looking at the troposphere, a region that should have warmed if climate models are correct in their projections and that has not been the case to the extent that the climate models have indicated.

Senator SESSIONS. Mr. Chairman, I know Dr. Jorgenson indicated that the cause is uncertain and there may be even more need to act, but there are certain things that we can know with certainty. That is, if we spent more money on emergency rooms and certain medical treatment programs, we could save large numbers of lives. So we have to decide what we're going to expend our resources on as a Nation.

We're talking about a major environmental commitment when we may have little, if any, benefit from it when we know there are alternatives that we could expend our resources on that would preserve benefits.

You see the situation about the Third World. How many lives would be saved if throughout the Third World there were electric generating plants as good as the ones in the United States, polluting somewhat, but how many lives would be saved if they had cheap electricity as we do in the United States.

That's really all I have to say. I'm interested in this subject. I consider it important for the Nation and the world and hope to learn more about it as we go.

Senator CHAFEE. Thank you, Senator.

Senator Warner.

Senator WARNER. Thank you, Mr. Chairman.

As you know, I've associated myself with the efforts of Senator Byrd and others on this issue. The main reason I've done so is couched in the question I'll put to all members of the panel.

Given that the current negotiations are focused on stabilizing and reducing greenhouse gas emissions from developed nations only, has the Intergovernmental Panel on Climate Change determined if there will be any discernible—that's the word I use, maybe there is a better one—discernible environmental benefit in terms of the amount of projected temperature increase or sea level rise as a consequence from implementing these proposals only on the developed nations?

Dr. Christy or Dr. Schneider, why don't you start off?

Dr. SCHNEIDER. I want to make sure I understand the question. The discernible benefit of?

Senator WARNER. If you just apply it to the developed nations and not the undeveloped, is there any likelihood there is going to be any benefit?

Dr. SCHNEIDER. Yes. I think there would be several benefits but it would not be an optimal benefit.

Senator WARNER. Not a what?

Dr. SCHNEIDER. Not an optimal one. It would be much better to have everybody play. In that sense, I agree with you, but let me clarify that. I'll try to do it briefly.

If nobody takes a first step, there will never be a step. Who should take the first step, one would assume that those people in a more economically favorable position to do so, and that's been considered in the world forum to be at least the richer nations.

The second reason is that since the richer nations have contributed the largest amount of cumulative emissions, that is, if you look back between now and what's been emitted over the last century, the bulk of what's out there is due to our activities.

In the future, that will change, there is no question of that, but we got the problem started. We had the victorian industrial revolution which even if powered by dirty power sources led nonetheless to an improved standard of living and there are other countries that would like to copy us in doing that.

They see our attempts to impose higher prices on them as trying to prevent them from doing what we were freely able to do and we polluted and now we're asking them not to. I think in that sense, there is a fairness argument.

However, you're all correct in saying that if we continue the policy of just having small segments of the world reducing emissions, that would not have nearly the impact as otherwise, so what we're trading off is essentially an efficiency versus equity argument.

If you'll indulge me in a cliche, I agree in this sense with the Byrd resolution, that everybody has to play for us to be effective but not necessarily everybody has to pay. We can argue that within the next couple of decades China will have larger emissions than the United States, but that will be in absolute terms, not per capita terms. Therefore, we could, in the sense of the planetary bargain in the international forum, argue about what is fair for the distribution of cost. Certainly you cannot have the developing world as nonplayers for a long time and then make a difference.

Senator WARNER. I think we've got your perspective. Anyone else?

Dr. JORGENSON. Yes. I'd like to chime in on this. I think the important thing is to think about the time dimension for policy. You and your colleagues every year have to consider taxes, you have to consider the budget, every year.

Senator WARNER. We try to do it every other year. You're speaking to very senior members of the tax panel when you look at the chairman and ranking member of this committee.

Dr. JORGENSON. Right, but this is something that was considered in 1992 and ended up with the treaty that was ratified by the Senate in 1994. We are now 3 years later if there is a treaty proposed in Kyoto, it will take a while to ratify. I would say it's something that will extend over a period of about 5 years.

There will undoubtedly be further climate negotiations. That's the point. Bringing in the developing countries is going to have a time dimension to it that will provide opportunities to take advan-

tage of the benefits of having those countries play. Who pays remains to be determined by the negotiations.

It's not something that is a matter of great urgency and it's not a reason that we ought not to take action now. We will sacrifice some efficiency but that is going to be very, very modest. What we ought to focus on is setting in course a process that will bring those countries into the negotiating arena and get them to be players at the appropriate time.

Senator WARNER. Dr. Lindzen.

Dr. LINDZEN. Yes. Could I answer it briefly? If you do not bring in China, no matter what you believe about climate——

Senator WARNER. You say if we do not bring China in?

Dr. LINDZEN. If you do not bring in China and India, no matter what you believe about climate, the impact on climate will be very little.

I guess I hear underneath what you're saying is, the reason you want to do something is to see how people would respond to such regulations to get a better idea. That may be an advantage, but the advantage will not be for climate due to these actions.

Senator WARNER. I thank the chair.

Senator CHAFEE. Thank you.

Senator Sessions, do you have any other questions?

Senator SESSIONS. Again, I'm troubled by the thought you're willing to sacrifice some efficiency but I've learned in the 6 months or so that I've been here that group after group after group comes before the U.S. Government and ask, it only cost a little bit to do this program or this regulation only increases costs a minimal amount, so incrementally pretty soon you have hampered this Nation's ability to be competitive in the world.

We already are losing large numbers of jobs around the world. I think, I for one, want to know that there is identifiable sound science that indicates to a significant degree we can improve this global climate before we take action.

Would anybody like to comment on that and correct me if I'm wrong in my thoughts?

Dr. Schneider.

Dr. SCHNEIDER. I certainly agree with you that we need to base all judgments on sound science, but we have a definition problem. Sound science does not necessarily mean certain science. To me what sound science means is the best judgment of the state-of-the-art of the community of the range of possible outcomes.

That is what these reports (e.g., IDCC) try to do and in that communication, there is always a fair degree of uncertainty. As I said earlier, that uncertainty includes mild and catastrophic outcomes as relatively low probability possibilities and almost everything else in between more likely.

As we continue to do more research, hopefully we'll be narrowing those ranges of uncertainties but everybody agrees they won't narrow that rapidly. Therefore, the question is whether we fear more investing present resources as you said, which have many good competitive uses, as a hedge against some potential risk in the future or whether we fear more the investment or whether we fear more having those risks unfold.

What Dale Jorgenson was suggesting is a modest policy to get started is probably a good way to go. I personally share that view. It is an experiment on how well we can do things and it is absolutely essential to reevaluate after every assessment which pops up every 5 years—in my testimony I refer to them as "rolling reassessments."

We must continue to reassess, knowledge may change of both the climate system and its impacts and the economic costs as new technologies are developed and we need a policy instrument flexible enough to crank up or down our concern as new information occurs.

Senator SESSIONS. Dr. Lindzen.

Dr. LINDZEN. I think Steve likes to emphasize the consensus on certainty and he always likes to point to a survey where I suggested there was less uncertainty, at least if I had to make a best guess.

The authors of the study, which Steve never quotes, point out that the behavior they see for the consensus is a herd instinct, not a scientific instinct. I think one issue we'll have to deal with in time, and I think John has been contributing to that, is we've had for over 20 years the estimates being based on models and the assumption that one of them must be right. It hasn't changed in 20 years.

As Steve said, what has changed is they put in different forcing by assuming that. That is a horrendous state that we haven't focused in 20 years on pinning down this answer better. I think some efforts are beginning to go toward that.

I think if you listen carefully to what you've heard here, you'll find that John finds it's not warming. The models say it should be warming throughout the atmosphere. Steve says let's look at the surface.

If you wanted to focus, you'd say if there is a discrepancy between the air and the surface, the surface then is not greenhouse. You'd begin to focus on the problem, pin down the science and get a firmer answer. I think we have to be worried about a science that isn't doing that for 20 years.

Senator SESSIONS. Dr. Barron.

Dr. BARRON. I was just going to say if you believe you should control emissions, I think the developed countries have to go first or else you're not going to get any of the other countries to follow.

I also agree if you don't get China and India involved in there eventually, the impact is going to be minimal.

Senator CHAFEE. When you say the impact will be minimal?

Dr. BARRON. The impact on mitigating the projected climate change.

Senator CHAFEE. The impact to the other nations.

Dr. BARRON. Yes. I asked a class of 200 students every semester to take all the numbers from emissions from different countries and the United States and come up with a strategy that would reduce them. It's practically impossible.

Tell you the truth, I personally, even though I also agree this might get us some efficiencies and learn how to do things, I personally don't think we're going to be successful until there are emergencies.

I suspect that the strategies we should involve ourselves in are ones that are adaptation oriented. I think the focus we have to take is to balance the economic issues that people are talking about against the vulnerabilities to all these changes and include natural variability. If you're vulnerable to natural variability, then I think it suggests you have to make an investment in these directions.

Dr. JORGENSON. Could I underline my agreement with what Dr. Barron just said? The real issue in this area, Senator, is adaptation. That's the most important, single issue we need to focus on.

What we've been focusing on here to a good extent is the need for mitigation. I've stated I think there is a need for mitigation, but if you ask where the dollars are, where can we do the most good, there's no doubt adaptation is far more important and mitigation is something that has to take second role.

Dr. SCHNEIDER. May I briefly add to that. There's an area where mitigation and adaptation become almost the same thing.

For example, suppose it turned out that the damages were at the more serious end—I would give that a coin flip, I don't know in advance whether it's going to come out on the less or more serious end—suppose we get a dramatic event or several events in the weather that mobilized public opinion rightly or wrongly, demanding urgent action and like the OPEC embargo, and the damages to the economy were done because of the sharpness of the price rise, not because of the price rise itself. Long-term benefits came from the price rise but there was significant damage from the sharpness. To return to my point, if sudden events came along and the politics changed and there was action with dramatic reversal of the nature of the energy system (e.g., from coal to solar or nuclear), I think that would be vastly more costly than if it were to take place slowly.

So one potential form of adaptation is an R&D policy. Whether that's direct subsidies or taxes or cap and trade or other factors as I discuss in the appendix to my written testimony and others can address, but if we could invest now in making those future alternatives both possible and cheaper, then you avoid the potential risk to the economy should that 50 percent eventuality come out that people want to really control the climate problem more so in the future and you wouldn't be hurt as badly.

In a sense, it is also adaptation to do that development of the alternatives that allow you to mitigate at a lower cost in the future.

Senator SESSIONS. I would just say it seems to me from what I've heard, and I'll be studying this with my staff and reading the transcript, but it seems to me what you're saying is it's uncertain that we have global warming. No. 2, it's pretty certain that if we act unilaterally, it's not going to have any impact on the environment.

I'm worried about working Americans who would bear the cost of a policy that wouldn't be effective if it were implemented. I guess that's my troublesome position.

Senator CHAFEE. Dr. Lindzen, if I understand what you're saying, it seems to me that your point is it doesn't make any difference what we do.

Dr. LINDZEN. It depends on what you mean not making a difference. I'm saying if you believe models that say we're going to get four degrees warming by 2100, which is well in excess of what the

Intergovernmental Panel on Climate Change is saying, then if you were to reduce emissions to 20 percent below 1990 levels, which as everyone seems to agree, we can't do, you would end up maybe with three degrees instead of four degrees.

I'm saying if you expect two degrees in 2100, we're not sure, then the proposed policy which is again, this exceedingly difficult policy, might bring it down to 1.6. At that point, you're already at the level of natural variability.

However you view natural variability, we've shown we can adapt to it, so I'm saying yes, no policy discussed and no argument made so far would, if you believed in global warming, stop it.

Obviously, if you think that global warming is not occurring, it also has impact, but I make the point in my testimony if our successors 50 years from now find there has been very little warming, and we do introduce stabilization, the one thing we can be sure of 50 years from now is if there wasn't warming, it was not due to the stabilization. It was due to our overestimate of the sensitivity.

Dr. JORGENSON. But there is a very important point I think needs to be added and that is, among the different alternatives that Professor Lindzen just rehearsed, the economic costs differ enormously. The economic costs of reducing emissions to something like 20 percent below 1990 levels are astronomical by comparison with the benefits.

Therefore, what we need to do is focus on something that is far more modest. That, I think, is what you should take away from this, that if we take the uncertainties that are involved and balance the cost against the benefits, we need to take a modest step, not a dramatic step.

Senator CHAFEE. It seems to me that we don't know. There is a lot we don't know about all this. However, there does seem to be some global warming taking place. If that is so—I think it is so—then we ought to do what we can about it.

Your point is there are some modest steps we can take that aren't going to wrench around the economy and devastate it but that would have some effects. I take it, Dr. Lindzen would say those steps you're suggesting don't amount to much. Is that unfair?

Dr. LINDZEN. No, that's unfair. I'm saying more than that. I'm saying what Dale is proposing, take the scenario you expect four degrees, that would knock it down to 3.95. We couldn't measure that impact, we couldn't even tell that it had an impact. So you're engaging in a policy where no one can assess whether you did anything.

Dr. JORGENSON. I beg to differ. If you look at Figure 5.4 in my testimony, the effect on global mean temperature in the year 2105, which is the end of this graph, it's a good bit more than that under the policy I would propose. It eliminates about 10 percent of the warming that would otherwise take place.

Ten percent is not a dramatic number. It's not 100 percent. That is Professor Lindzen's point and I agree with him, but I think you shouldn't underestimate the changes that would be required and that can be justified on economic grounds.

I would say we need to focus on adaptation but there are steps to mitigate the effects of climate change that could have the effect of reducing some of the global warming. They are not, as Professor

Lindzen wants to emphasize, steps that will end global warming. We are going to have some global warming if these figures are correct.

Dr. LINDZEN. Could I ask for one change in vocabulary? We're using warming in two senses. We're using it in the passive sense of change of temperature and we're also using it in the active sense of man having done something to warm the atmosphere.

So far there's data that suggests there's been very modest, passive warming of the climate system over the last century. As the IPCC made very clear, we're having almost no luck in being able to attribute anything of this to man's activities.

I think if we could be careful in the use of the word warming to distinguish the two rather than mixing them.

Senator CHAFEE. Wait a minute. That's quite a statement you're making. If I understand what you're saying, it's yes, indeed, the globe has warmed up, temperatures are higher but it's due to passive activities.

Dr. LINDZEN. No, no. I'm saying it's a matter of the English language. We used the word "warm" to mean change of temperature and we also use it as an active verb meaning we have caused something.

I'm saying the passive part is the temperature has changed a little bit. It really has been a little bit. Half a degree centigrade is what the temperature change is while you wait for the street light to change.

On the other hand, the IPCC has been very clear that they have been unable to tell what fraction of that very small temperature change has been due to man's activities. So we've been unable to pin down what we're doing to it.

Dr. CHRISTY. I'd like to add something there. I was on that panel that looked carefully at the temperature record of the past and we included a statement in the IPCC that this century was the warmest of the past six. That's not a very remarkable statement when you think about it, but you looked at the data that we did have available to us but we're not quite as sure about, centuries in the past were warmer than the present century.

You go from one century to the next and there are large changes. The 21st Century will be different than this current one. It's definitely the case that the 19th Century was unusually cool. Bouncing back from that, as Dr. Lindzen said, is part of the natural variability which is why in my comment earlier, I made the statement that most of what we've seen is due to natural variability.

Dr. BARRON. You just don't know whether we're bouncing back from anything.

Dr. SCHNEIDER. How do you know we're bouncing back? How do you know it wasn't stopped by the increase of emissions from initial deforestation and industrialization? You're presupposing you know the climate is random. We don't know that. That's what we're interested in figuring out.

Dr. CHRISTY. We're looking at temperatures that were warmer in past centuries than today.

Dr. BARRON. But how do you know that it wouldn't have continued?

Senator CHAFEE. What does he know what wouldn't have continued?

Dr. SCHNEIDER. That the recovery is in fact a recovery. Maybe it's induced. We don't know that. That's one of the difficult issues where it might be partly related to some changes in the energy output of the sun. There are a number of aspects we can debate. That's what we're trying to figure out, the relative amounts, but you can't presuppose that the recent variations in the system are all natural.

Once we know that humans started changing the land surface and started changing the atmosphere, which we began to do significantly in the 18th Century, so we cannot actually rule that potential influence out yet. That's part of the debate.

Dr. BARRON. The objection occurs when he says the world is bouncing back from an unusually cold period. It's just as possible, because of the way natural variability works, that it was in the midst of bouncing to an even colder century and therefore we have an even bigger problem than we're thinking.

By saying that, he's presupposing he knows the mechanisms and the way natural variability works.

Dr. CHRISTY. I would say most of that occurred before these events you're talking about affected the climate.

Dr. SCHNEIDER. I'm not saying humans created a little Ice Age. What I'm arguing is that it's often said this is just the recovery from that. Well, it's the recovery but that doesn't mean that there wasn't a human component of that recovery and that's what we're trying to figure out.

Dr. CHRISTY. There's a variance about that and that's what we said here earlier.

Dr. SCHNEIDER. The word modest has been the word of the day and it's a very good word and it's one to which I subscribe. I'd like us to have some modesty also as I said earlier, and let me reinforce it, about let's not underestimate what the technological capacity and the inventive genius our society is.

If engineers and the companies of the world, with I think some government involvement as well—and that balance is for you to decide—made it a determined plan to find alternative technologies that could produce the service—we're not interested in whether it's carbon dioxide, we're interested in energy, the service that counts—we can abate carbon cost effectively.

If we could produce the service by alternative means at lower prices, then some combination of economic and ecological environmental wisdom would move us in that direction, but those technologies don't invent themselves.

Therefore, what we're talking about is what are the modest policies that can help us as an insurance policy to develop those technologies so we have that standby capacity should the future lead us to, by bad luck, more serious outcomes.

Let me recall Dale's presentation—with Dick and Dale arguing about how many tenths of a degree would be saved by various optimized policies. Tim Roughgarden, an undergraduate student who is in our senior honors program at Stanford, took a look at the Nordhaus climate energy-economy model and instead of using the damage function that Bill did—the 1 percent loss of GDP—we used

five published damage functions from other economists, ecologists and others and he found there is about a factor of 10 difference in their estimate of climate damages.

The amount of carbon tax varies by a factor of five in the optimum calculations just depending upon which one of those damage functions you used. We don't know the answer to which is correct yet and there may even be others.

Therefore, the amount of climate change policy response needed substantially varies depending upon what you assume about climate damage. I hope our modesty extends to also understanding that optimal tax calculations have a very wide range of uncertainty and there are many estimates that are much larger than those used in Bill Nordhaus' study for which there is a substantial scientific justification, although you can also justify the more modest kind. Therefore, flexible instruments seem to be the most important message of the day.

Senator CHAFEE. In that quote you had from that certain Senator Chafee, I think it was 10 years ago?

Dr. SCHNEIDER. Nine.

Senator CHAFEE. As I recall, it was about doing something. We don't know what's happening, but we'd better plan. Don't take the rosiest view, take a different view because it might occur. Could you read that quote?

Dr. SCHNEIDER. Sure. I'd be delighted to.

> If there is one point I could make, Mr. Chairman, it is this. There are a great many questions about the greenhouse effect that can't be answered today, but I don't think we ought to let scientific uncertainty paralyze us from doing anything. It is always convenient to find an excuse not to do something and there is always an excuse out there not to do something. I think the issue before is what steps should we be taking today to help solve the problem in addition to doing more scientific research.

That was your quote from the Senate Energy Committee testimony in 1988.

Senator CHAFEE. I approve of that quote.

Do you have anything else, Senator?

Senator SESSIONS. I would like to ask one question. Are you satisfied as a Nation and the world, have we properly focused on establishing the best science that we can to answer where we are and do we need to do anything to improve our scientific gathering of evidence?

Dr. JORGENSON. Senator, you came in, as you said, after some of the presentations, but a number of people quoted a Washington Post piece by Robert Samuelson that appeared yesterday and that is also in the current issue of Newsweek in which he presented his view of the economics of the problem.

I think great advances in the economic understanding are called for. He was talking about measures that would involve a $100 tax on carbon as opposed to the kind of measures that I've been talking about which are $10, a totally different order of magnitude.

Although I think a great deal of progress has been made in the science, I think there is a great deal of need for better economic understanding.

Senator SESSIONS. Dr. Christy, is anyone asking you from the Environmental Protection Agency?

Dr. CHRISTY. Give me more satellites and data.

Senator SESSIONS. And you think you could determine whether or not this is happening?

Dr. CHRISTY. The upper atmosphere or the tropics, that's an area where we have little understanding. Climate models are clearly in error in that region. Balloon networks are falling apart around the world. This is an international problem when you're talking about surface observations.

Data is becoming very hard to get from other countries and that hurts us in trying to understand how the system varies. So if those barriers can be reduced and a systematic measuring system carried forward, that would be my goal.

Senator SESSIONS. Dr. Lindzen.

Dr. LINDZEN. Yes. I have a slightly oddball suggestion, but I think if you want to solve problems with science, you need a stable funding base for science so that scientists do not feel that if a problem gets solved, there goes their funding.

Senator SESSIONS. Time and again, we do have groups come in from various independent agencies and you wonder if they all got together under good leadership and hammered out these differences, could we reach a consensus.

Mr. Chairman, thank you for having this hearing. I congratulate you on your leadership on this issue over the years.

Senator CHAFEE. Thank you.

Let me ask one final question if I might. The question is, do you believe we know enough about the prospect of climate change to embark upon a program to address it, some program? I'm not saying *x* billion but some program in order to address it?

Dr. BARRON. I personally think a combination of what we know about the potential for human-induced changed and what we know about natural variability suggests to me there is a lot of practical, maybe what you'd call win-win things that you can and should do, so I do think you need to embark on something.

Basically, I look at this as say the issue is health and you see the health is tied to both natural variability and potential for climate change, it suggests that surveillance efforts on some of these viruses, on the distribution of vectors, the mosquitoes, an ability to have advanced warning systems, and public awareness are all things that become logical for which you can substantially reduce what the risk is and it helps you adapt.

The same thing occurs in water resources. If you're sitting there and you're in a state and you're living on the edge of your resources, and in the case of natural variability, you go through tremendous hiccups, problems or issues in terms of the availability of the resource just by natural climate variability, I think it makes sense to have some call to action there.

In a lot of cases, it's win-win in the sense of the benefits you'd get in not having the natural variability affect you to such great degree, but we also discover that, for instance, industry collocates with water availability.

Right now, in every single State in this Nation, they use, withdraw from streams about 25 percent of the available resource and there's a big difference in the availability of resources across this Nation. That means the industry is sitting there locating next to rivers and the same thing occurs for recreation.

So if you're at risk, just a natural variability and you see this risk extends also to climate change. I think there is a good reason to something now, but these are protection against adaptation and the expectation that in doing something now, you've saved yourself money.

Senator CHAFEE. Dr. Lindzen.

Dr. LINDZEN. I think what Eric has said is hard to disagree with. Fundamentally, one is saying no, we don't know—we know enough right now to know there is no action we will take that will change what will happen vis-á-vis climate, but there are actions we can take to make our society more robust.

As has been said in the past, if you can think of things that are worth doing anyway, my argument has been to justify them on what they will do anyway. I think the difficulty here is there may be things that can make the society more robust to climate change. There is very little we can do to affect whether there will be climate change or not.

Senator CHAFEE. Dr. Schneider.

Dr. SCHNEIDER. You called on us to make a conclusion, which as you know, is a value judgment, namely do we fear more investing present resources against something which might happen or do we fear more letting it happen without trying to slow it down.

Then you said how much information does it take for us to make such a judgment. That's exactly the same question of how much information does it take to decide how much insurance to buy or how much national security to buy through military investment. This is exactly that same kind of problem.

I'm a risk averse person. I have earthquake insurance. A lot of my colleagues don't, living in California and the question is, how much of it do we want to purchase.

Frankly we've been talking about what we've been saying over the last 20 years. I thought we had enough scientific information 20 years ago to do the kinds of policies Eric Barron talked about, namely make ourselves less vulnerable to the natural kind of variability. Dick Lindzen says, "Well, do that but don't say it's climate."

I would disagree with Dick in this sense. I would say, "Do a little bit more as the insurance premium to deal with climate change." I'm willing to make that investment personally and try to convince people out in society they should make that small investment in that insurance premium at the scale of our planet to reduce the likelihood of the negative outcomes. If we can make those investments in something that makes sense anyway such as developing alternative energy systems that have less air pollution, that can be cheaper in the future and be more reliable, so much the better.

Dr. JORGENSON. Senator Chafee, I'd just like to sum up my remarks. As you suggested, I've already laid out my proposals but let me be explicit about it.

One thing we could do right away that would have a major impact and is a "win-win" situation is to eliminate $14 billion in energy subsidies through the Tax Code and through our expenditure programs that distort energy markets in the direction of using too much energy.

Second, in terms of the Kyoto Summit, here is where we come to Senator Sessions' very well taken point. We have an opportunity

to act in a way that is not unilateral. That's the point. It doesn't make any sense to think about what I'm about to say on a unilateral basis, but at Kyoto we have the opportunity to bring about some kind of international agreement.

That would involve the kind of ideal agreement about a $5 tax beginning immediately on carbon. That's a very modest step but it's one I would add to the $14 billion in subsidy removal.

Senator SESSIONS. How would that translate on a gallon of gas?

Dr. JORGENSON. That translates to about 5 cents on the gallon.

Let's focus on what we should recommend to China by our diplomatic efforts and by efforts at the Kyoto Summit. We should urge China to do what, in the last 10 years, almost every developing and formerly socialist country has done, which is to move energy prices to world levels.

That would have a tremendous benefit to China, it's a win-win for them; and to the world economy. It's a win-win for the rest of us as well.

I think there are concrete steps we can take and that would be my list of three.

Senator CHAFEE. Thank you.

Do you list in here where that $14 billion comes from? Is that in your testimony?

Dr. JORGENSON. That is not in my testimony, I'm sorry to say. That is a study that was done by the Department of Energy and I'd be happy to provide a reference and I'll send it to you.

Senator CHAFEE. Could you? That would be helpful. Thank you.

Dr. Christy.

Dr. CHRISTY. To answer your question, it's a fairly vague question so I think I could vaguely say yes, if you include the conservation efficiencies and improved technologies and so on, that kind of program would be worthwhile.

I agree pretty much with the generalities that have been stated thus far.

I would say I use less energy today than I did before because I have a daughter in college and that requires me to not be able to spend as much on doing things and buying stuff. So that's my level of conservation at the moment. I think it will improve.

Senator CHAFEE. We thank you all very much for coming.

[Whereupon, at 12:58 p.m., the committee was adjourned, to reconvene at the call of the chair.]

[Additional statements submitted for the record follow:]

PREPARED STATEMENT OF ERIC J. BARRON, EARTH SYSTEM SCIENCE CENTER, THE PENNSYLVANIA STATE UNIVERSITY, UNIVERSITY PARK, PA

The prospect of future human-induced climate change represents perhaps one of the most challenging science and society questions of the century. There is no doubt that humans are altering the environment—both in terms of the land surface and the composition of the atmosphere. In particular, greenhouse gases (carbon dioxide, methane, nitrous oxides) in the atmosphere have increased substantially in concentration over the last several decades.

The best scientific assessments available suggests that the impacts of these changes will be significant, yet the error bars, or uncertainties, are also very large. The real question is how should society respond when the best available science suggests that human activity may substantially alter climate, but at the same time the scientists are seriously debating the magnitude, timing and distribution of the climate changes. Answers to this question depend on two basic sources of information, climate observations and model predictions.

THE OBSERVATIONAL RECORD

Looking first at the observational record, we see continuing debate on its nature. Much of this debate has centered around differences between satellite derived estimates from the Microwave Sounder Unit (MSU) and surface thermometers. The surface observations indicate that recent years have been among the warmest since the late nineteenth century, with 1995 being the warmest on record. The rate of warming from these observations is .13°C per decade. This is in contrast to MSU interpretations of −.05°C per decade. The differences have lead to spirited debate. For example, Hurrell and Trenberth (1997; Nature) have suggested that the negative trend in MSU observations is due to errors when merging records from different MSU satellites.

We are beginning to see distinctive surface signals in precipitation and temperature that separate the later part of this century from the earlier part of the century. Karl et al. (1996; Bulletin of the American Meteorological Society) provide an analysis of U.S. data from precipitation and temperature from 1900 to 1994—see figure 1 below. These diagrams illustrate substantial trends in key climatic parameters.

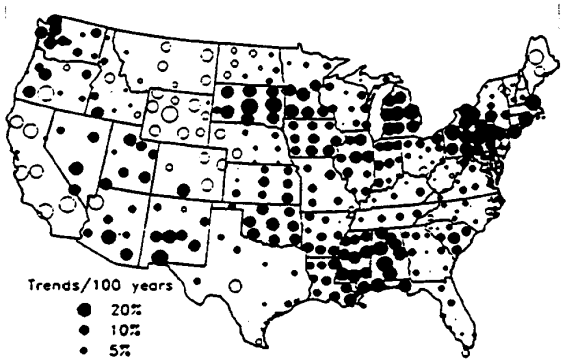


Figure 1a. Precipitation trends for the United States. Solid circles represent increases in precipitation and open circles, decreases. The size of the circle indicates the magnitude of the increase or decrease.

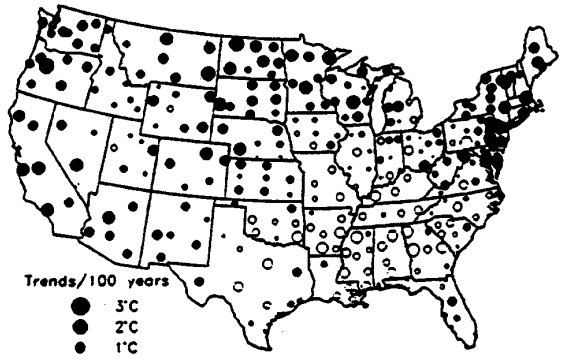


Figure 1b. Temperature trends for the United States. Solid circles represent increases in temperature and open circles, decreases. The size of the circle indicates the magnitude of the increase or decrease.

Karl's analysis also indicates (figure 2) that there has been an increase in the amount of precipitation from extreme precipitation events (daily events at or above 2 inches of rainfall).

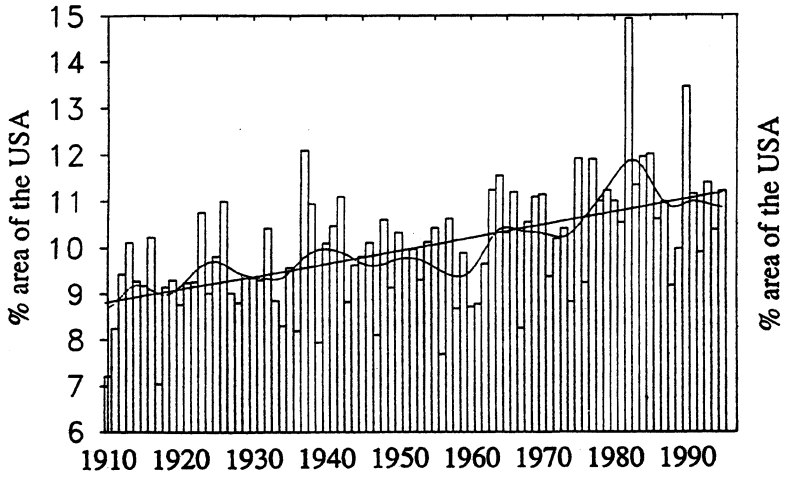


Figure 2. Percent area of the USA with a much above normal proportion of total annual precipitation from extreme precipitation events [daily events at or above 2 inches (50.8mm)]

Combined land and ocean surface temperatures (figure 3) provide the basis for examining global trends in temperature, and are the basis for speculation on the importance of anthropogenic greenhouse gas increases as an explanation of the warming. These analyses indicate that global-mean surface temperatures have increased by .4 to .60°C during the 20 Century.

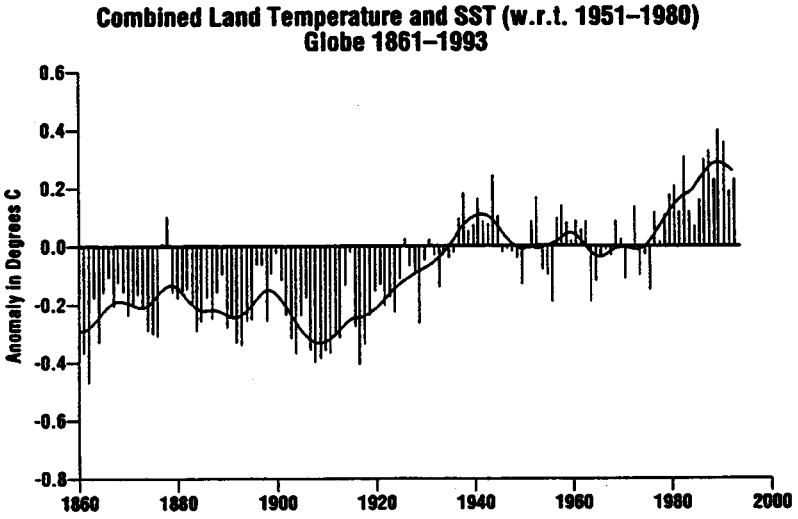


Figure 3.

However, our observations of climate change from instrumented records are very short, and they rely on systems designed for weather prediction—not one designed for taking the temperature or pulse of the earth. We lack continuity of satellite observations, surface instruments are subject to change and the level of accuracy is based on weather safety and forecasting needs and not global temperature analysis. Geologic records from ice cores, tree rings, corals and other sources of data suggest that the Earth's climate is naturally highly variable. The record of snowfalls on Greenland (figure 4) illustrate this variation during the last 18,000 years. Changes in snow accumulation rate are often abrupt, suggesting remarkably large climate changes over periods of decades.

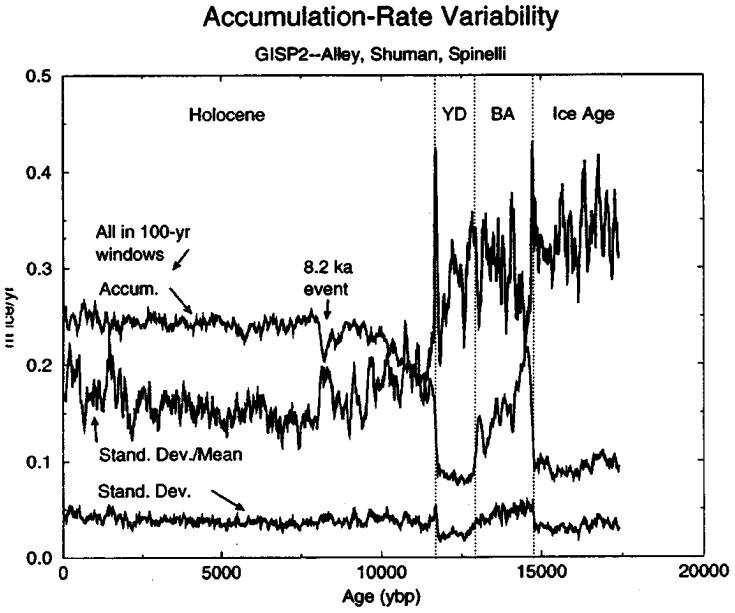


Figure 4. Greenland snow accumulation rates

Tree ring data are equally intriguing. For example, Jacoby et al. (1996; Science) report on Mongolian tree rings which indicate much wider tree ring widths for the recent century—a phenomena associated with warmer annual temperatures. The 20th century warming appears to be unique over the last 450 years (Figure 5).

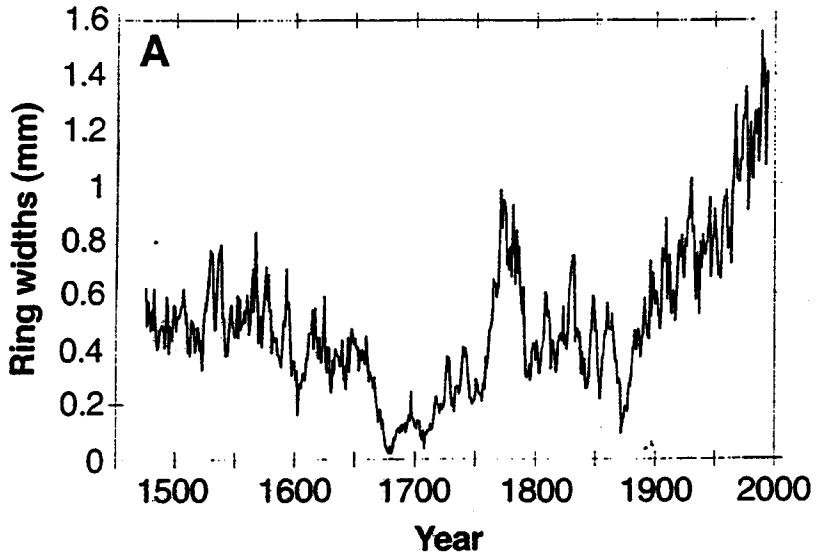


Figure 5. Ring widths for the last 450 years from Mongolia illustrating a unique 20th century record indicative of warming.

The recent record appears to be unique, but the simple fact is that modern humans haven't experienced the range of variations which occur naturally, nor do we have a real sense of their character or spatial distribution. The record describes change, but without clear attribution as to the causes. Significant natural variability should be expected during the coming decades.

RESULTS FROM MODEL PREDICTIONS

The results from model predictions also have limitations. In large measure, scientists agree when the topic is global and the predicted changes are given as a range (e.g., a doubling of CO_2 will yield 1 to 4.5°C globally averaged temperature warming), but we have greater and greater uncertainty when we look at specific regions, specific decades or specific phenomena, such as changes in hurricane intensity or numbers. Yet it is at these scales that human systems intersect and interact with climate.

The reprint that follows is a summary of predictions from climate models with a "ranking" of the uncertainty associated with the predictions. The rankings are based not on some specific criteria, but rather the considered opinions of a large group of climate experts who have sought to place model predictions in an ordered context which would readily be understood by the educated United States citizen. Within the text are two figures which illustrate results from comprehensive climate models. Figure 1 in the reprint illustrates the range in predicted changes in global-mean surface temperature, in degrees Celsius, for the next 80 years based on results from seven different General Circulation Models (the most comprehensive climate models to date) with carbon dioxide increases included at the rate of 1 percent per year (IPCC 1995 assessment). All seven models suggest an additional 1 degree global-mean increase in temperature by the year 2050. Figure 2 in the attached reprint gives the predicted geographic distribution of an increase in mean-annual surface temperature that would result from a doubling of carbon dioxide based on the GCM simulation of Manabe and Stouffer (1994; Journal of Climate). Increases for the United States range from 3 to more than 5°C. The predicted changes are substantial given that the 1988 heat wave and drought in the Ohio River Basin was on average less than 1°C above normal.

Climate model experiments designed to predict past climates, which are very different from today also yield valuable insights. During the last decade, hundreds of GCM simulations have been completed by a wide variety of models in an attempt to predict climates both substantially warmer and substantially cooler than at present. In no case did a GCM overpredict the warming or the cooling in the geologic record. This suggests that the GCMs may have a sensitivity to factors such as carbon dioxide which is less than that required to explain past climates. Other factors may also be important (e.g., identification of all the factors which may have influenced past climates and difficulty in extracting correct climate information from fossils), but the fact that the models always have underpredicted the changes in the past may be telling. It is also interesting to note that the major warm episodes during the past are also associated with geochemical evidence for higher atmospheric carbon dioxide levels.

The reprint which follows details the strengths and weaknesses of current modeling programs nationally and internationally. It also notes that progress on both observational and modeling fronts over the last decade have been clear, but it is a mistake to promise quick answers. Solution of many of the remaining issues will undoubtably take decades. I suspect that for many years to come, newspapers will continue to explain topics like global warming by quoting scientists who are poles apart on specific points. Yet in the midst of the public confusion that this approach promotes, we can't ignore the fact that even within the range of climate model predictions, the consequences have significance for our economic vitality and national security.

CONSEQUENCES
THE NATURE & IMPLICATIONS OF ENVIRONMENTAL CHANGE

AUTUMN 1995
VOLUME 1 NUMBER 3

Climate Models: How Reliable are their Predictions?

By Eric J. Barron

We often hear the assertion that our extensive use of carbon-based fuels now threatens to alter the climate of the whole world: that enhanced greenhouse warming—induced by the carbon dioxide and other gases we have added to the air—will lead to a rapid and unprecedented rise in the average temperature of the Earth within the next fifty years.

We are not accustomed to long-term forecasts of anything of such consequence. Nor can it be surprising that the initial reaction of almost anyone is to question the reliability of the prediction. For what is claimed—if indeed an accurate portrayal of the future—seems to leave few choices: do we prepare ourselves for the impacts of lasting climate change? Should we rethink our own use of coal and oil and natural gas and gasoline, when energy use, as we all know, is very much tied to economic growth?

What must trouble many decision-makers is that the sounding of this loud environmental alarm was tripped not so much by measurements as by computer models. How certain or how controversial are these largely theoretical predictions of global warming, and on what assumptions are they based? Given the potential importance of regional climate changes for the development of national policies, and the impacts of extreme, climate-related weather events such as droughts, floods, and hurricanes on agriculture and human safety, how reliable are the projections of future change? Are the uncertainties in present climate models so great that we can ignore their predictions? What elements are the most robust? Are there prospects for substantial improvements in climate models in the near future?

These questions, so often asked, were put to a group of scientists in late 1994 in response to requests from both the White House Office of Science and Technology Policy (OSTP) and from the Government Accounting Office (GAO) which was responding, in turn, to a request from Congressmen John Dingell of Michigan. The charge to the Forum, which I chaired at the request of the U.S. Global Change Research Program, was to develop a statement on the credibility of modeled projections of climate change, to provide background to the government for considering and developing national policy options. The participants

Prof. Eric Barron is an atmospheric scientist who directs the Earth System Science Center at the Pennsylvania State University in State College. He now serves on the National Research Council's Committee on Global Change Research, Board on Atmospheric Sciences and Climate, and as chairman of the Climate Research Committee. This article summarizes the conclusions of a Forum, chaired by Dr. Barron, that responded to requests of the GAO and OSTP.

included climate modelers and other knowldgeable scientists who were chosen to bring to the Forum a wide spectrum of scientific opinion regarding the potential threat of global greenhouse warming. This review provides the author's summary of the Forum report, which is listed as a reference at the end of the article.

BACKGROUND

General circulation models

Computer-run, mathematical simulations or *models* of the atmosphere and ocean are the principal tool for predicting the response of the climate to increases in greenhouse gases. The most sophisticated of these, called *general circulation models*, or *GCMs*, express in mathematical form what is known of the processes that dictate the behavior of the atmosphere and the ocean. GCMs include the interaction of the atmosphere with the oceans and with the surface of the Earth, including plants and other ground cover. They allow us to test, by mathematical simulation, what should happen to climate, around the world, in response to a wide variety of changes. For example, what climatic effects would follow a major volcanic eruption, or a change in the radiation from the Sun?

All of the GCM experiments designed to assess the impact of increases of greenhouse gases point to global warming through the coming century, with accompanying changes in rainfall and other meteorological quantities

The great power of mathematical models lies in their ability to simulate the behavior of systems—like the atmosphere and ocean—that are too complex or extensive for simple, intuitive reasoning. There are limits, however, to how much complexity can be handled by the computers on which the models are run. At present, models of the global climate system cannot include physical processes whose horizontal dimensions are less than several hundred miles—a constraint that imposes simplifications on how well we can model what we know and restrictions on the amount of regional detail. The key is to incorporate the best possible representation of all the important processes and feedbacks necessary to characterize the climate system, while keeping within the practical capabilities of modern computers.

Our ability to evaluate the strengths and weaknesses of climate models has grown over the last two decades. A growing number of GCMs, many with independently derived components, are available for intercomparison. We have a growing store of meteorological and oceanic observations against which model predictions can be tested. We also have information on past climate change, recorded by natural processes in rocks and sediments, that allow us to assess the ability of models to replicate the known features of climates different from that of the present day. Each of these elements is the basis for debate on the reliability of climate model projections of the future climate.

Consensus predictions

All of the GCM experiments designed to assess the impact of increases of greenhouse gases point to global warming through the coming century, with accompanying changes in rainfall and other meteorological quantities. Still, the complexity of the climate system is a tremendous obstacle to predicting future climate change. Neither climatological observations nor present climate models is sufficient to project how climate will change with certainty. A workable approach is that adopted by the Intergovernmental Panel on Climate Change (IPCC) of the World Meteorological Organization and the United Nations Environment Programme, which is based on projections of the expected growth of greenhouse gases and the combined results of many GCMs. In terms of mean global surface temperature, the consensus prediction of the IPCC is for an increase of 0.5 to 2° Centigrade (about 1 to 3.5° Fahrenheit) by the year 2050, in response to an anticipated increase of 1 percent per year in CO_2. The low end is a significant change; the high end, a dramatic one. Moreover, were the amount of atmospheric carbon dioxide to double, the consensus forecast is for an eventual warming of 1.5 to 4.5° C (about 3 to 8° F.)

Such changes, if realized, would represent a significant climatic change. For example, the most recent climate change of similar magnitude was the last major Ice Age that reached its peak about 18,000 years ago. The mean global temperature during that time is estimated to have been between 3 and 4° C cooler than at present. The effect of this small a change in global-mean temperature can be appreciated when we realize that during the last Ice Age, glacial ice—a mile or more deep—covered much of North America, year-round, reaching as far south as the Great Lakes and the surrounding states of present-day America. That amount of change in global-mean temperature is similar, although opposite in sign, to what is now projected due to increases in greenhouse gases. But the rate of change is not. The last Ice Age developed over thousands of years, while global greenhouse

warming is projected to occur within a span of less than a century. And within the lifetime of people now living.

It is equally clear that in terms of potential impact, the difference between a 1.5° and a 4.5° C projection for future warming is very large. As a result of this uncertainty, decision-makers are confronted with a difficult question. What steps should be taken when the best indications from state-of-the-science models suggest that climate change due to human activities may be large and significant, yet the predictions are less than certain?

The scientific debate regarding these uncertainties has entered the public arena, providing considerable confusion even for those aspects of climate-model predictions that are virtually certain. The debate over how much warming—and by when, and why it hasn't yet been more clearly seen—has clouded the clearer picture that increases in carbon dioxide will raise the global-mean temperature. It has also affixed the stamp of "controversial" on almost any reference to impending global warming in the press and news media, implying, erroneously, that the general concept, and not just the details, is in serious doubt.

A method for evaluation

It is possible to get an indication of the strength of a building or other structure if we know which of its footings are solid and which are less so: in this case, to separate the aspects of predicted climate change that are virtually certain from those that are uncertain. The Forum carried out this kind of assessment of predicted global warming, to provide better illumination for policy discussions and to assist policy development.

The evaluation is divided into three parts. The first provides a basis for any discussion of climate-model predictions by identifying the foundations of the greenhouse warming theory that are most solid and robust: a series of conclusions which can be viewed as "virtually certain" based on observations, experiments, and the results of many models. The second part is a listing of specific predictions of climate models that are societally important, ranked by degree of certainty. In the last part we examine what can be done in the future to improve climate-model predictions.

The Foundation

Although the specific predictions of climate change are derived from models, the reasons for expecting significant global warming in the near future comes from a much deeper foundation that includes laboratory and field experiments, well-established knowledge of atmospheric behavior, and measurements that include worldwide monitoring of atmospheric conditions. Here we list seven of the principal scientific arguments for a global-warming prediction. Throughout, the stated conclusions are subject to little or no debate because of their level of certainty, and indeed, to some they may appear trivial.

First, as confirmed in laboratory experiments, certain gases that are naturally present in small amounts in the atmosphere play an active role in maintaining the Earth's temperature. They do this by absorbing energy (*infrared radiation*) emitted from the land, ocean, clouds, and the atmosphere itself, and then re-emitting it. The most important of these so-called greenhouse gases are, in order, water vapor, carbon dioxide, and methane, followed by nitrous oxide, ozone, and *chlorofluorocarbons* (or *CFCs*), which are manmade compounds of chlorine, fluorine and carbon.

Second, because they absorb radiated energy, increased concentrations of greenhouse gases will inevitably raise the Earth's temperature. The extent of the warming will depend on possible amplifying or damping mechanisms (*feedback processes*), particularly those involving water vapor and clouds, that are major players in controlling the natural greenhouse effect. Such feedbacks can change the magnitude of the warming, but there are no known cases where they bring about an opposite, cooling effect. Thus that greenhouse-gas increases will produce warming is not in question. The heart of the greenhouse debate concerns the nature and timing of temperature increase, and the associated changes and impacts of other climatic quantities, not the fact that increases in greenhouse gases will lead to a rise in global temperature.

Third, the amounts of carbon dioxide, methane, nitrous oxide and chlorofluorocarbons present in the air today are significantly higher than their "pre-industrial" levels—that is, the amount that was present, naturally, before the intensive use of energy that began with the Industrial Revolution about 200 years ago. For example, the amount of carbon dioxide that is measured in the air throughout the world today is about 30 percent greater than that found in years before about 1800, as determined from the chemical analysis of air trapped in well-dated, polar ice cores. Similar findings apply to methane (which has increased by more than 100 percent) and to other greenhouse gases, with the possible exception of water vapor. The increases can be tied directly to human activities that include fossil-fuel burning (as for heating, or in internal combustion engines), the burning of trees to clear land, and certain agricultural and industrial practices.

Fourth, it would take hundreds of years for the concentration of carbon dioxide to fall back to pre-indus-

trial levels, even if the amount emitted were immediately and substantially reduced around the world. The reason is the slow pace of the natural processes that remove carbon dioxide from the atmosphere. Further, the projected growth in world population and energy use in the developing countries make it highly unlikely that any substantial reductions in total global carbon-dioxide emissions will take place over the next several decades. Thus the atmospheric concentration of carbon dioxide is expected to continue to rise well into the 21st century. Similar arguments apply to most other greenhouse gases.

Fifth, there are many more microscopic, airborne particles (known as *aerosols*) in the atmosphere than were present in pre-industrial times, concentrated in and downwind of areas of intensive human activity. Aerosols are present naturally in the atmosphere in the form of windblown dust from cultivated soils, hydrocarbons from vegetation and forests, and soot from forest and grassland fires. What has increased is the *anthropogenic* or human-made contribution: soot, sulfate aerosols and other particles found downwind from regions of intensive fossil-fuel combustion and biomass burning.

Sixth, laboratory and atmospheric measurements demonstrate that *sulfate* aerosols (containing compounds of sulfur and oxygen) that come either from volcanic eruptions or fossil-fuel combustion exert a cooling influence on the climate, by reflecting some of the incoming solar radiation back into space. The increase in airborne particles cited above could thus offset some of the warming expected from the buildup of greenhouse gases, although the magnitude and extent of aerosol cooling is not known and is difficult to quantify, in part because the regional distribution and character of past and future emissions of aerosols are poorly known.

Seventh, the globally averaged temperature at the surface of the Earth has risen about 1° F (or 0.5°C) in the last 100 years. Because of the natural variability of climate, the change cannot yet be ascribed unambiguously to the increase in greenhouse gases over the same period. Nor is the recorded temperature rise as great as that expected, based on climate-model results, from greenhouse warming, although some or all of the difference may be due to the cooling effect of aerosols, noted above, or to the action of other competing long-term effects.

These seven findings form the basis for the conclusion of a vast majority of scientists that human activities are now modifying the energy balance of the Earth system. Less certain are the magnitude and the timing of the associated climate changes, which are derived from models and which are the subject of considerable debate.

Climate Model Predictions

Predictions of future climate are imperfect because they are limited by significant uncertainties that stem from: (1) the natural variability of climate; (2) our inability to

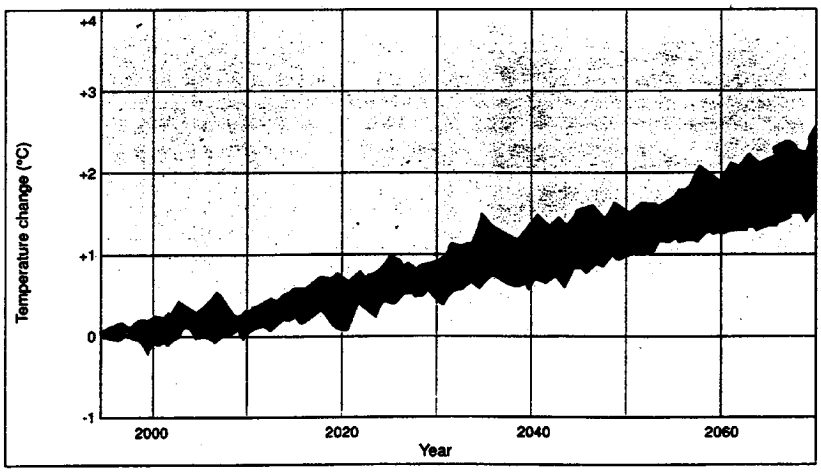


Figure 1 The range of predicted changes in global-mean surface temperature, in degrees C, for the next eighty years, shown as a band bounded by the upper and lower extremes of seven different GCMs, each of which assumed an increase of 1 percent per year in CO_2.

predict accurately future greenhouse-gas and aerosol emissions; (3) the potential for unpredicted or unrecognized factors, such as volcanic eruptions or new or unknown human influences, to perturb atmospheric conditions; and (4) our as-yet incomplete understanding of the total climate system. The reliability of climate-model predictions depends directly upon each of these.

With this in mind we list below, in order of certainty, the major policy-relevant predictions of present climate models.

Calculated changes in climate variables will obviously depend upon the assumptions made regarding the future concentrations of greenhouse gases in the atmosphere, which are a function of projected population growth and associated economic expansion. The modeled results that are given here assume that greenhouse-gas concentrations in the atmosphere will continue to increase in coming decades. For purposes of simplicity, the climate-model used considers only carbon dioxide and assumes that it will increase 1 percent each year, which, for purposes of calculation, replicates the effect of the anticipated increases in the concentrations of all other greenhouse gases.

A Ranked List

In ranking its conclusions, the Forum adopted a system of four levels of certainty, as these terms are defined in general usage: virtually certain, very probable, probable, and uncertain.

Virtually Certain:

1. The temperature of the *stratosphere*—an upper region of the atmosphere that extends from about ten to fifty kilometers (six to thirty miles) above the surface of the Earth—will be significantly cooled. This cooling comes about through the combined effect of increases in carbon dioxide and the observed depletion in stratospheric ozone, and the manner in which the two gases absorb and re-emit energy. Opposite in sign to what is expected near the ground, the change had been predicted by models and has now been observed. As such, it provides potential early evidence of greenhouse warming.

Very Probable:

2. The surface temperature of the Earth will continue to rise through at least the middle of the 21st century. The prediction is based on (a) projected, continued increases in greenhouse-gas emissions; (b) the results from a host of model calculations; and (c) the analysis of past climates of the Earth. The best available estimate, from the international assessment by the IPCC and based on the range of available model predictions, is that the global-mean surface temperature will increase by about 0.5 to 2° C (roughly 1 to 3.5° F) over the period from 1990 to 2050 (Fig. 1). For comparison, an increase of 0.5° C—the lower

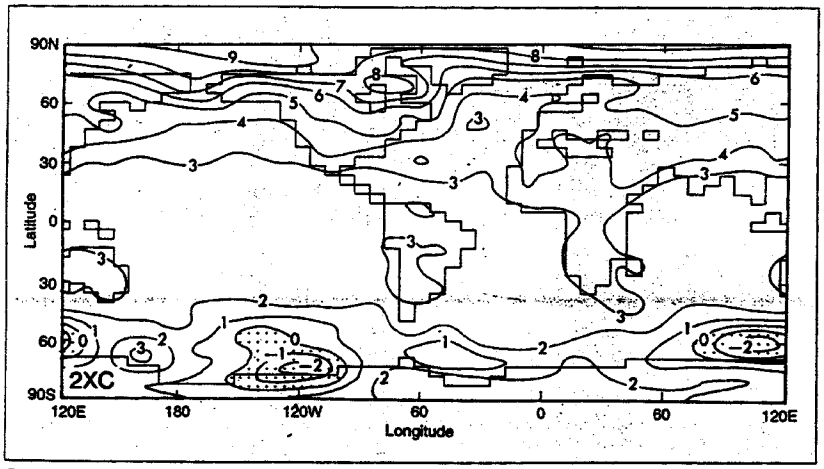


Figure 2 An example of the expected geographical distribution of an increase in annual-mean global surface temperature that would result from a doubling of the present amount of CO_2 in the atmosphere. Contours are in degrees C. From the GCM simulation of S. Manabe and R. J. Stouffer, Journal of Climate, vol 7, pp 5-23, 1994, with permission of the American Meteorological Society.

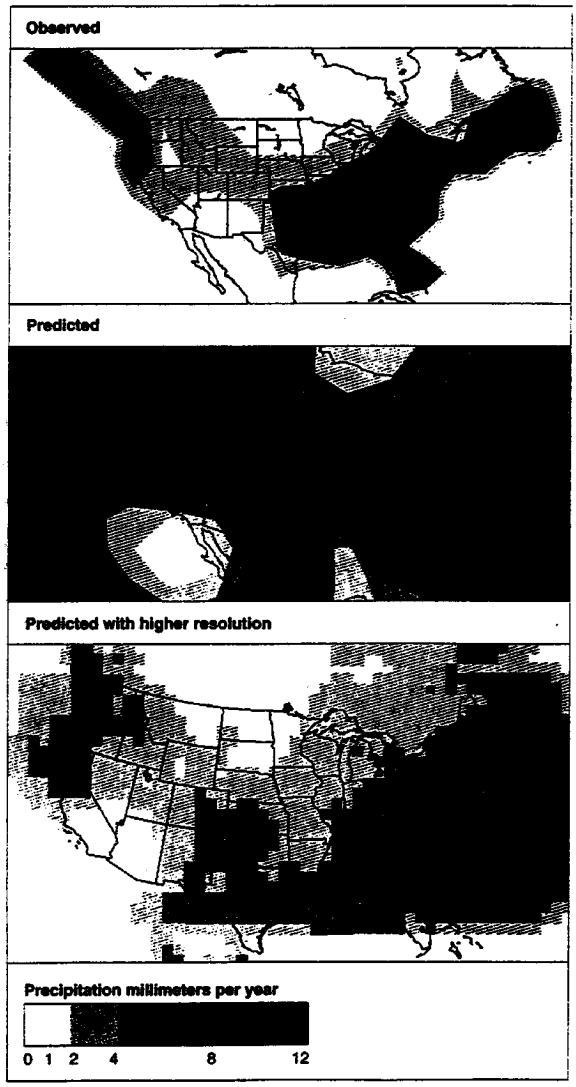


Figure 3 A comparison of observed and modeled precipitation over the U.S. for the spring of 1980, illustrating the potential for improved predictions with higher spatial resolution. *Top:* Observed precipitation, March through May. *Middle:* Predictions for the same period using a conventional GCM, illustrating the large regional errors that accompany broader-scale agreement. *Bottom:* Predictions from a model that utilizes significantly higher spatial resolution. Contours are in millimeters of rainfall. From G. Jenkins and E. Barron.

limit—is equal to the warming that has taken place in the past 100 years. Beyond the year 2050, the carbon dioxide concentration is expected to reach twice that of pre-industrial times. When that level is reached, and after the climate has reached equilibrium, the best estimate for the resulting climate change is a warming of 1.5 to 4.5° C (about 3 to 8° F). The IPCC considers a mid-range increase of 2.5° C (5° F) the most probable result. The model calculations assume that the present levels of sulfur aerosol emissions (for example, from the burning of soft coal) will to some degree diminish in years ahead; if they do not, the temperature increase will be somewhat less. The actual temperature change could fall outside the ranges given here should natural climate variations happen to be large during the period of the prediction.

3. Higher surface temperatures will cause an increase in the average precipitation over the globe. This comes about because temperature affects the rate at which surface water is evaporated (to return to the ground in the form of rainfall and snow). While the connections between temperature and precipitation rates are well understood, the distribution of changes in precipitation over the Earth is less certain.

4. The amount of sea ice in the Northern Hemisphere will be diminished. Studies of past climates provide evidence for the polar amplification of either global warming or global cooling. The reason is a positive feedback loop that connects warming (Fig. 2, p. 21), reduction of sea ice, replacement of the highly reflective sea ice with a darker and more absorbing ocean surface, and

hence additional warming. For these reasons, it is very probable that the extent of sea ice in the polar regions of the Northern Hemisphere will be reduced by melting. Changes in corresponding areas of the Southern Hemisphere are less certain due to differences in ocean circulation and the presence of the Antarctic continent.

5. Land areas in the Arctic should experience amplified wintertime warming. The positive feedback loop noted in point 4 above also applies to the land. The magnitude of the surface warming there will also depend on how the normal transfer of heat by the atmosphere from the equator to the pole responds to global warming, and this point is uncertain.

6. Global warming will cause sea level to rise. This is expected as a consequence of three temperature-related changes: the physical expansion of sea water as the ocean temperature increases, the partial melting of mountain glaciers, and changes in the extent and thickness of the Antarctic and Arctic ice sheets. The expansion of sea water can be determined from the projected temperature change described above. Reasonable estimates of the retreat of mountain glaciers are also available, but calculations of the changes expected in polar ice caps are far less certain. Based on calculations of sea-water expansion and the retreat of mountain glaciers, and ignoring the possible long-term response of the polar ice caps or any potential catastrophic collapse of the west Antarctic ice sheet, it is estimated that global sea level will rise from 5 to 40 centimeters (2 to 16 inches) by 2050. This projection compares to an anticipated rate of sea-level rise of 2.5-12 centimeters (5 inches) if currently observed rates of rise over the past century continue.

7. The climatic effect of any changes expected in the amount of energy radiated from the Sun in the course of the next fifty years is much smaller than that from increased concentrations of carbon dioxide and other greenhouse gases. Based on current knowledge, the Sun's energy output varies by about 0.1 percent over the eleven-year sunspot cycle, and this variation can affect the surface temperature of the Earth. However, the effects of anticipated greenhouse warming are four to seven times greater than those that could result from these short-term changes in the total flow of energy from the Sun. Were the Sun's radiation to fall to the lowest levels yet measured and to remain there through the next fifty years, it could diminish the expected effects of greenhouse warming by about 25 percent. Were solar radiation to remain abnormally high throughout this time, which is about equally likely, it could add to the effect by at most the same amount.

Probable:

8. Continental dryness will increase at middle latitudes in summer in the Northern Hemisphere. The basis for this prediction is the fact, cited earlier, that higher temperatures lead to much higher rates of evaporation: in net effect, the increase in evaporation will on a regional basis exceed the accompanying increase in rainfall. The amount of drying is qualified, however, by several factors that are not well represented in models. These include the movement of evaporated moisture from place to place through atmospheric circulation; the effects of changes in ground cover due to the response of vegetation to increased carbon dioxide; the role of aerosols; and interactions between the land surface and the atmosphere, including the storage of wintertime precipitation in soils.

9. Rain and snow at high latitudes will increase as the amount of moisture in the atmosphere is increased. The freshwater that is added there by precipitation could alter the deepwater circulation of the oceans, which is driven in part by differences in the salt content of different parts of the ocean and which in turn affects climate. Additional precipitation could also affect the size of the polar ice caps, and hence perturb sea-level.

10. The Antarctic and North Atlantic Oceans will warm more slowly than the global average. Changes in sea-surface temperature are moderated in regions such as these because of the regular mixing of the surface water with the deeper, cooler water of the ocean. They are thus the most logical sites for slower-than-average warming. The sea-surface temperatures there, however, will also depend on accompanying changes in precipitation and freshwater inputs that can change the rate of vertical mixing of the oceans.

11. The occasional eruption of a major volcano will temporarily diminish global warming, but for no more than a few years. Historical records indicate that the solid particles introduced into the stratosphere by volcanic eruptions can cool the mean temperature of the Earth by a few tenths of a degree C for up to two or three years, during which time the particles are removed from the upper atmosphere. Such changes would constitute transient interruptions in the longer-term trend of greenhouse warming.

Uncertain:

12. Changes in climate variability will occur. However, the exact nature of changes in climate variability due to greenhouse warming is as yet not well defined. All models predict a possible reduction in wintertime variability in warmer climates; it is also commonly predicted that thunderstorm activity should increase as a result of the increased moisture content of the atmo-

sphere. The frequency of El Niño events could change as a result of a global warming, as could the frequency of atmospheric "blocking" events that set up persistent weather patterns that last weeks to months at a time.

13. Changes in the climate of regional-scale areas (from the size of large metropolitan regions to the scale of states or small countries) are likely to be quite different from the global average. We have only a very limited capability to estimate changes expected in the climate of any specific region. The spatial resolution of climate models is, as yet, too coarse to incorporate effects such as regional land characteristics, surface contours, and local hydrologic conditions, even though these factors are known to be important. Regional changes in climate can differ from global changes, but the nature of the probable differences is uncertain.

14. The intensity of tropical storms, including hurricanes, may increase. This can occur as a result of the effects of the higher sea-surface temperatures that are associated with global warming, because tropical storms derive their energy from temperature differences. However, there are simply too many unresolved issues—such as how possible changes in the poleward transport of heat may influence the amount of tropical warming—to predict more precisely what the effect will be. Whether the number of such tropical storms will also increase is also uncertain, in part because GCMs are not run at spatial resolution fine enough to simulate hurricane formation.

15. Forecasts of climate change over the next twenty-five years are as yet uncertain. Although such forecasts are much to be desired, present uncertainties in the factors that control the natural variability of climate, in the model simulations, and in expected changes in atmospheric chemistry make it extremely difficult to predict decade-to-decade changes in climate. In any given decade, the changes in temperature and related variables could be substantially less than or more than the predicted long-term trend. Warming estimates in terms of degrees per decade and the use of these trends to analyze a single decade are unwarranted and misleading.

16. Interactions between climate and vegetation may modify the magnitude of predicted greenhouse warming, but whether these effects will amplify or diminish climate change is as yet uncertain. The limited assessments that have been made suggest possible feedbacks due to climate-induced changes in vegetation, such as the replacement of high-latitude tundra by vegetation more characteristic of temperate latitudes, or the displacement of forests by grassland. Other cli-

mate impacts can result from the direct effects of enhanced carbon dioxide on plant growth, from impacts of tropical deforestation, and from the effects of plant productivity on atmospheric chemistry.

Steps To Reduce The Uncertainties In Present Models

The uncertainties cited in the list above can provide a set of ordered priorities for improving present climate models. Given the compelling need for clearer answers, we can count on continued improvements. Yet, for many reasons—including the need for additional observational data—significant reductions in many of the uncertainties will require sustained efforts over a decade or more.

Much of the research effort of the multi-agency U.S. Global Change Research Program is designed to address the uncertainties cited here, including those that involve cloud-radiation-water vapor interactions, ocean circulation, aerosols, natural climate variability, land-surface processes that include vegetation changes and chemical cycling, the frequency and intensity of high-impact events such as hurricanes, factors that create the potential for surprises, and the interaction between chemistry and climate.

Seven areas of improvement are described below that are likely to reduce uncertainties in GCM predictions over the coming decades. These should be viewed as opportunities for significant improvement in climate-model predictions.

1. **The use of finer spatial resolution in climate models** (see Fig. 3, p. 22). Many of the uncertainties associated with the results of climate models stem from the relatively coarse *spatial resolution* that they employ—that is, the smallest element of the landscape for which input can be provided, or results obtained. In the present use of GCMs this is often 5° in latitude by 5° in longitude, or a square approximately 350 miles on a side, which is about the size of New Mexico or all of New England. Many advantages accrue at higher resolutions: storms and circulation patterns, for example, are significantly better represented—in part because of improved representation of land contours and characteristics, and in part because of the capability of including major weather-system processes. The same arguments apply to the ocean component of climate models.

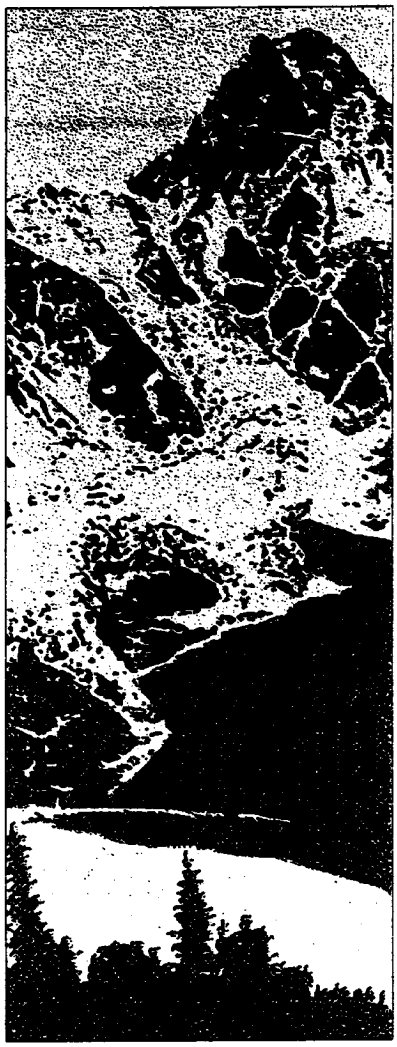
The use of finer resolution comes at the costs of longer computing time and greater data-handling requirements. Switching from a 5° x 5° grid to one with a resolution of 2.5° x 2.5° requires substantially more computing time. Each time the spatial resolution is doubled, eight times more computer time is required on the same machine. A calculation with 5° resolution might typically take ninety hours of continuous running on today's fastest supercomputers; the higher-resolution run would tie up the same supercomputer, night and day, for almost a month! It is not only cost that holds back the use of higher resolution: in many cases not enough is known about detailed processes to utilize a finer grid. The combination of increased availability of computer resources and of studies that elucidate the physical processes at finer resolution are very likely to bring substantial improvements in climate-model capability. They will also provide the opportunity to tailor predictions to specific regions.

2. **Improved representations of the lowest layer of the atmosphere (the often turbulent and so-called *boundary layer* in which the temperature and contours of the ground surface affect the moving air) and of the distribution of water vapor throughout the atmosphere.** Significant improvements in the first of these depend, at present, on a better understanding of the science of how air moves under the particularly complicated conditions at the air-land interface: where, in a sense, the rubber meets the road. How much water vapor is in the air and how it is distributed geographically and with height above the surface is another major source of uncertainty in model predictions, because of its dominant role in determining the temperature of the atmosphere. The distribution of water vapor is highly variable, temporally and spatially; improvements in modeling the effects of water vapor await observations more extensive and more accurate than those currently available.

3. **Improved representations of the connections that link the atmosphere, the ocean, and the surface of the land.** In Nature, each of these affects—and is affected by—the other two. In most of today's models, the real connections that link them together are approximated by arbitrary adjustments or are characterized by large uncertainties. Were we able to include more-accurate representations of these processes, we could use climate models to explore the causes and characteristics of natural climate variability on all time scales. The focus of GCMs was initially on atmospheric processes. Corresponding improvements in the representation of the land surface and the connections between the ocean and the atmosphere are likely to result in substantial model improvements.

4. **More explicit representation of the land surface, including vegetation, soil characteristics, and effects of enhanced levels of carbon dioxide and ozone on plants.** Modeled estimates of soil moisture, summertime continental drying, and regional climate

change depend very much on how accurately the land surface is represented, including more explicit treatment of vegetation of all kinds. All of the known processes that link the atmosphere with the biosphere, or the atmosphere with the soil, are interactive or two-way connections, in the sense that each controls, to a degree, the other.



5. Continued comparisons of models with observational data and with other models. Important new data sets—for example, new, long-term, consistent observations from NASA's Earth Observing System and supplementary data sets now being developed that span the current century—can provide more critical tests of the accuracy of climate models. Progress in model development and improvement can be accelerated by comparisons of this kind, and through the continued intercomparison of the results of different models.

6. Demonstrated capability of climate models to simulate global changes of the past. The ability of a model to predict the climate of the future can be measured by its success in simulating what is known to have happened in the past. Data that describe significant global changes of the past—including the coming and going of the major ice ages and the climate changes of the last 1000 years—have been obtained through the analysis of tree-rings and the sediments deposited in dated ice and in lake and ocean cores. They provide an invaluable test of the reliability of climate models. Greater emphasis on the analysis of past climates can help assess model projections of climate sensitivity and variability, and lead to enhanced model credibility.

7. Improved representation of the interactions that link climate and vegetation with the concentration of greenhouse gases, and of the effects of aerosols on climate. Temperature, wind, and rainfall are involved in the ongoing exchange of chemical elements and compounds among the air and the water and the solid earth, thus affecting the concentration of greenhouse gases in the atmosphere. Changes in vegetation also affect the continual exchange of chemical elements among air and water and land, and the distribution of water. Aerosols, through their indirect influence on clouds and atmospheric chemistry, can also influence climate.

Conclusions

Three major conclusions can be drawn from this three-part examination of the capabilities and limitations of climate models. The first is that we know very well how greenhouse gases affect the energy balance of the Earth, and with similar confidence that the concentrations of these gases are now increasing due to human activities, and that these increases should result in global warming. At issue is not whether the Earth will warm, but by how much, where, when, and with what consequences for society and ecosystems.

Second, the level of confidence in the results from present climate models depends very much on the spatial and temporal specificity of the prediction. The most certain are those that pertain to the Earth as a whole and

that apply to a roughly fifty-year period. Regional predictions, predictions on a decade-by-decade basis, and predictions of higher-resolution phenomena such as hurricanes, are considerably less certain. For the decisions that we face as individuals, it would be much better were it otherwise, although a highly confident, general prediction with expectations of improved detail can provide a useful guide for broad policy decisions.

Third, substantial opportunities now exist, given consistent and long-term research endeavors, to improve the specificity of climate-model predictions. These include efforts to refine spatial resolution, to improve the physical representation of the lowest layer of the atmosphere, to provide more realistic representation of non-atmospheric components of the climate system, and to provide more critical tests of models, both among themselves and against new and more comprehensive observations of present climate and also data from the past.

Interestingly, the current focus on the policy relevance of climate models in the U.S. has often been negative: a view that climate models are far too uncertain to be used in setting costly economic or national security policy. The widely-publicized scientific debate over these uncertainties has resulted in considerable confusion, even in cases where the conclusions from climate models are robust. For policy decisions, it would seem far more helpful to understand the degree of certainty or uncertainty associated with the different elements that enter climate predictions.

Accurate near- and long-term climate forecasts carry the potential of tremendous economic and humanitarian value. An example of the potential value of advanced prediction is the recent successful use of coupled ocean-atmosphere models for El Niño forecasts to limit the impact of these shorter-term changes in climate on food production and fisheries. The prediction of long-term climate change using GCMs is more challenging than an El Niño forecast, although improvements in the former are likely to be of even greater economic value. Indeed, the importance of advance knowledge may well be the reason that Japan and countries in Europe are developing strong environmental observation and prediction efforts regarding impending climate change. The improvements in models, outlined above, can be viewed as a path toward more accurate climate predictions. In some cases, these predictions may serve as warnings in areas of societal vulnerabilities, such as food production or the adequacy of freshwater. In many cases, they will clearly contribute to economic vitality.

For Further Reading

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Forum on Global Change Modeling. USGCRP Report 95-02, 26pp, Washington, D. C., 1995. Available from USGCRP Coordination Office, 300 D St. SW, Suite 840, Washington, D. C. 20024.

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Scientific reviewers provide technical advice to the authors and Editor, who bear ultimate responsibility for the accuracy and balance of any opinions that are expressed.

EVALUATING POLICY DECISIONS BASED ON CLIMATE MODEL PREDICTIONS

Policy decisions about climate change are particularly challenging given that (1) the results from comprehensive climate models suggest significant changes over the coming decades, but the uncertainties are also large—particularly when examining the aspects of climate model predictions which are most significant for human activities and (2) the increased surface temperatures and changes in precipitation patterns recorded from surface instruments may be a result of human-induced climate change, but may also be a product of natural climate variations. Two types of actions address this conundrum.

(1) *We must ensure that we have a healthy observing system and modeling effort in this nation.* Obtaining useful climate records is a secondary priority of our current observing systems which has been designed for weather safety and prediction. Relatively modest increases in funding could address this issue. Programs designed to provide continuity of satellite observations (e.g., NASA Earth Observing System) are subject to annual review and budget reductions, increasing the risk that continuity of critical measurements will be lost. Interestingly, European countries and Japan are promoting strong space-based observation programs as they recognize the value of these data sets for decision-making and scientific advancement.

The U.S. climate modeling community has expressed strong concerns about the effectiveness of our efforts in climate modeling, with particular emphasis on the fact that IPCC assessments are increasingly being based on long-term simulations completed by other nations. Interestingly, countries like Japan, the United Kingdom and Germany are promoting strong observation and modeling programs with less robust economies than the U.S. The simple fact is that advanced knowledge has economic and societal value.

There is also considerable prospect for advances in knowledge, and at scales which allow us to examine more closely the potential impact of climate change on societies. For example, recent techniques have been applied to produce high resolution climate simulations by embedding or nesting high resolution, limited area climate models within global models. Global models provide the coarse spatial resolution predictions of the large-scale atmospheric circulation, while the high resolution model allows the incorporation of more realistic elevations and model physics. Figure 3 in the reprint illustrates the improvement in the prediction of precipitation for the United States comparing (a) observations for spring 1980, (b) a GCM prediction for spring 1980 showing a relatively poor simulation of this important variable, and (c) the results for the same period from a high resolution model embedded within the same GCM shown in figure 3b. The improvement is dramatic, giving confidence that higher resolution models may provide more useful predictions. Figure 6 illustrates the results from this technique for a doubled concentration of carbon dioxide. The results suggest substantial differences in precipitation (figure 7). Winter precipitation is predicted to increase in the Northwest and Northeast with modest increases across the northern states. California and Arizona show significant decreases in winter precipitation. In summer, the model simulation suggests the largest increases in precipitation occur from Louisiana-Mississippi-Alabama across the across the central U.S. to South Dakota. Again, California has significant decreases. Such results must be viewed with caution—they are a preliminary analysis using a new, and not thoroughly tested technique to achieve high resolution predictions for specific regions.

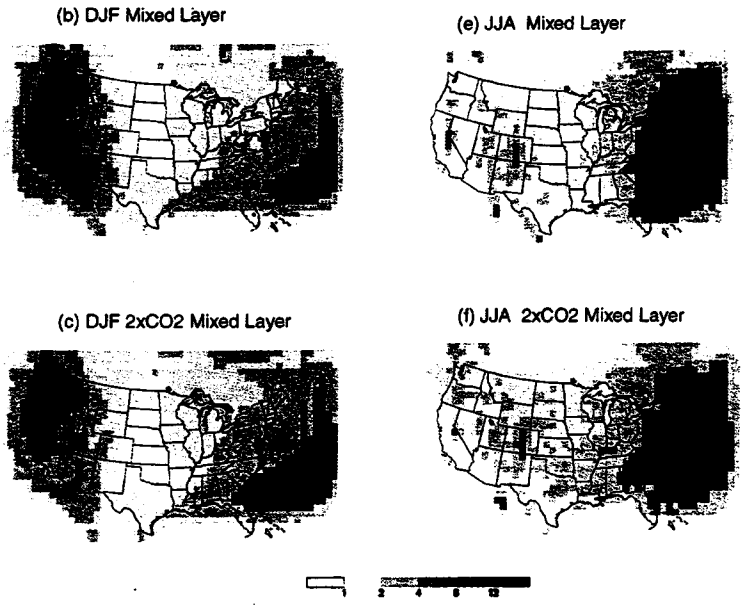


Figure 6. Precipitation Rates for DJF and JJA using the regional climate model. (b,e) Mixed layer ocean; (c,f) 2XCO2 mixed layer ocean. Units in mm/day.

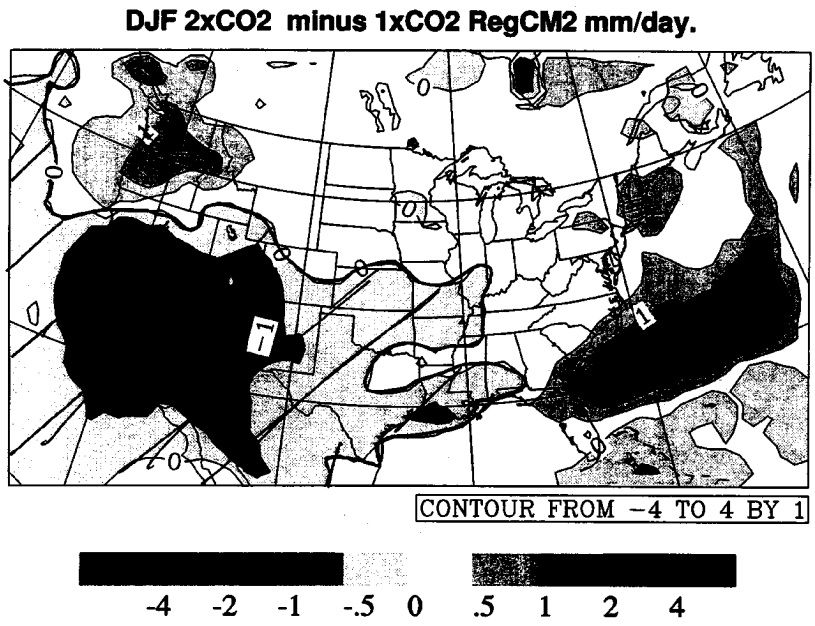


Figure 7a: Differences in precipitation (Doubled CO2 simulation minus present day simulation) for winter (December, January, February) in millimeters per day derived from a high resolution U.S. model embedded in a global climate model. Hatchered lines are hand drawn to aid in identifying regions predicted to have less precipitation in a doubled CO2 climate.

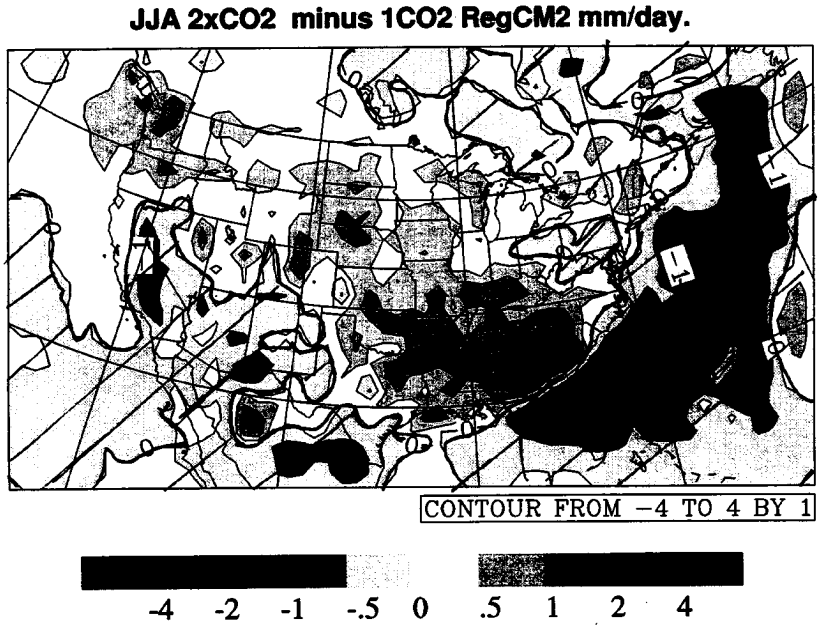


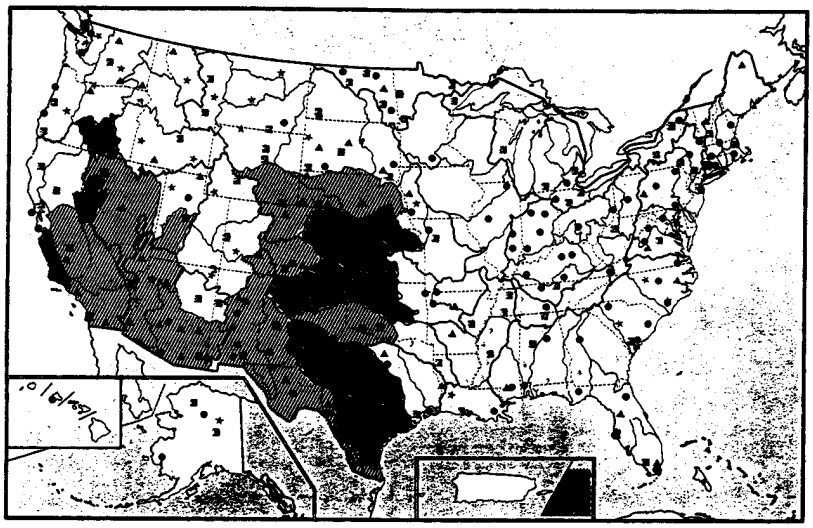
Figure 7b: Differences in precipitation (Double CO2 simulation minus present day simulation) for summer (June, July, and August) in millimeters per day derived from a high resolution U.S. model embedded in a global climate model. Hatchered lines are hand drawn to aid in identifying regions predicted to have less precipitation in a doubled CO2 climate.

(2) *We need to develop and apply a litmus test to action which is practical and most likely to achieve positive results. Risk and vulnerability to natural variability and climate change must be a key aspect of this test.* For example, if a region is already historically and economically vulnerable to droughts or floods, and predictions of fixture climate change also exhibit such tendencies, or even enhanced tendencies, then this should be a call to action. Water and water resources provide a key example of potential vulnerabilities. Two figures follow which describe vulnerability associated with water availability and water quality. Figure 8 illustrates regions with water demand problems in 1980. Each dot or shaded area indicates a problem where water demand approached or exceeded supply during the period of analysis. This suggests a vulnerability to natural variability and to climate change (see figure 1 and 7, for comparisons). Figure 9 illustrates water withdrawals by industry. Note that the industrial withdrawal of water is basically a percentage of the available resource (near 25 percent). This suggests that water is a critical resource to industry and that industry is co-located with water, using far more in regions where water is abundant. Many regions are susceptible to water quality problems as a result of climate variability or change. Interestingly, decreased river flow, or increased extreme events with decreased median rainfall events, has the potential to dramatically change the dilution power of rivers for pollutants. Water quality may be an unheralded global change issue.

Economic and societal risk should also be a key aspect of decision-making. For example, the emergence or re-emergence of infectious diseases, which are closely related to climate, have become an issue of growing concern in the health community. Human health issues have potential for tremendous costs associated with human life. Human health risks are governed by a large number of factors, ranging from socio-economic status, to the availability of clean water and nutrition, to the quality of the health care infrastructure—factors which generally serve to limit U.S. risks. However, over the last decade, climate and climate change have become recognized as one of the significant factors influencing health risk within the U.S. Climate change and variability can effect health directly, through extreme thermal events like heat waves and cold episodes, and through severe weather such as hurricanes and tornadoes. Climate change can also influence human health indirectly. The majority of the indirect influences involve (1) changes in the range and activity of vectors and infective agents, (2) changes in water and food-borne infective agents, and (3) altered food (especially crop) productivity. A number of examples of human health vulnerability in the United States serves to illustrate the nature of this problem.

The increases in average temperatures associated with global warming or with extremes in natural climate variability will probably be accompanied by an increase in the number of heat waves. The deaths of 726 people in Chicago during the summer of 1995 heat wave is an example of the potential direct impact of thermal extremes. Mid-latitude cities, already characterized by large urban heat island effects, appear to be the most susceptible to heat waves. The heat-related mortality that has occurred in cities such as Chicago, St. Louis, Washington D.C., and New York City disproportionally affect the young, elderly, the economically disadvantaged, and the ill.

Phenomena, such as El Niño, are associated with changes in rainfall, producing flooding and droughts in different regions. Based on climate model predictions, climatologists have speculated about whether anthropogenic warming will produce increased intensity or an increased number of severe hurricanes along the east coast of the U.S. Severe weather has well-known potential to increase the number of deaths and injuries.



Explanation

Subregion with inadequate streamflow ("1975"-2000)

70 percent depleted in average year

70 percent depleted in dry year

Less than 70 percent depleted

Specific problems *(as identified by Federal and State/Regional study teams)*

★ Conflict between offstream and instream uses

Inadequate supply of fresh surface water to support—

Offstream use

● Central (municipal) and noncentral (rural) domestic use

Industry or energy resource development

▲ Crop irrigation

Instream use

Fish and wildlife habitat or outdoor recreation

Hydroelectric generation or navigation

Boundaries

Water resources region

Subregion

Inadequate surface-water supply and related problems

Figure 8: (U.S. Water Resources Council-2nd National Assessment)

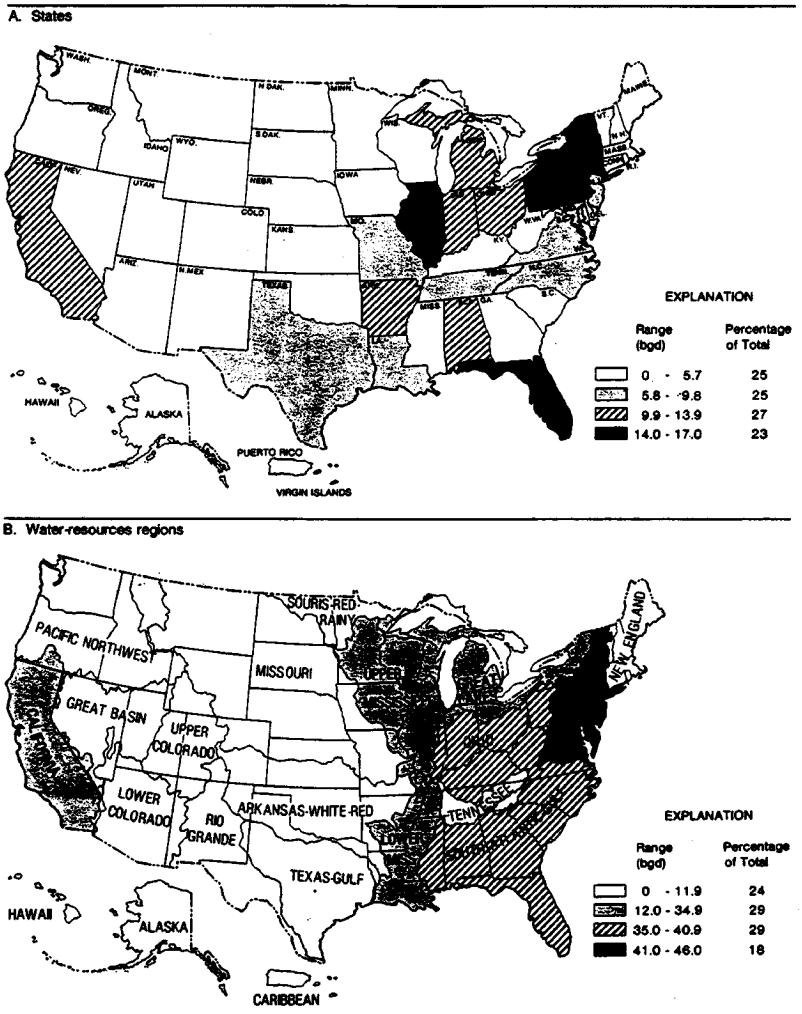


Figure 9: Self-supplied industrial water withdrawals, by States and water-resources regions, 1980.

Vector-borne diseases are a major cause of illness and death across the world. These disease vectors (e.g., mosquitoes and rodents) are strongly influenced by climate. For example, Dengue fever is transmitted by the bite of a mosquito (Aedes aegypti and Aedes albopictus). Both mosquitoes are currently present in Florida and Texas (an outbreak of Dengue occurred in south Texas in 1986) but U.S. cases are uncommon, most probably because of high standards of housing, adequate water, sewer and waste management systems. However, the mosquitoes that transmit Dengue are strongly controlled by winter temperatures. Warming, particularly in terms of minimum winter temperatures could substantially increase the range of this Dengue vector, including regions north of the mid-Atlantic states. Figures 10 and 11 show regions of potential outbreak, and the association of the Dengue vector with warm winter temperatures. Malaria, caused by the protozoan parasites of the genus Plasmodium and transmitted by Anopheles mosquitoes, would also substantially extend its range and activity under conditions of global warming.

Wet-Dry cycles also influence human health risks because of its influence on predator-prey relationships. Historically, moving into a wet period following a few years of severe drought, provides advantages to rodent populations which can reproduce faster that their predators (e.g., owls, etc). Population explosions of rodents eventually leads to invasions into human habitats and human food stocks, increasing the risk of disease. This is the primary explanation for the outbreak of the deadly Hanta virus in the Four-Corners region of the U.S. (figure 12).

Lyme disease, which is caused by a bacterium, has a strong climatic association as well. Lyme disease is transmitted by the bite of a tick (Ixodes scapularis) which feeds on the white-footed mouse, the white-tailed deer and other mammals. The number of Lyme disease cases is strongly correlated with the size of the deer population, and in turn, the size of the deer population is correlated with the severity of winter conditions in the northeastern U.S. (figure 13).

The U.S. is less susceptible to problems of malnutrition and crop productivity compared to much of the world because of the breadth of food production and our capability for technological adaptations. None-the-less, climate change and variability may result in the need to change crops and planting practices, and may also influence the activity or emergence of crop diseases.

Health risks associated with climate change and variability have implications for policy. Such policy should involve (1) surveillance efforts, (2) increased research on changes in range and activity of vectors associated with climate change, (3) disease prevention programs, (4) education for medical and public health communities, and (5) public outreach.

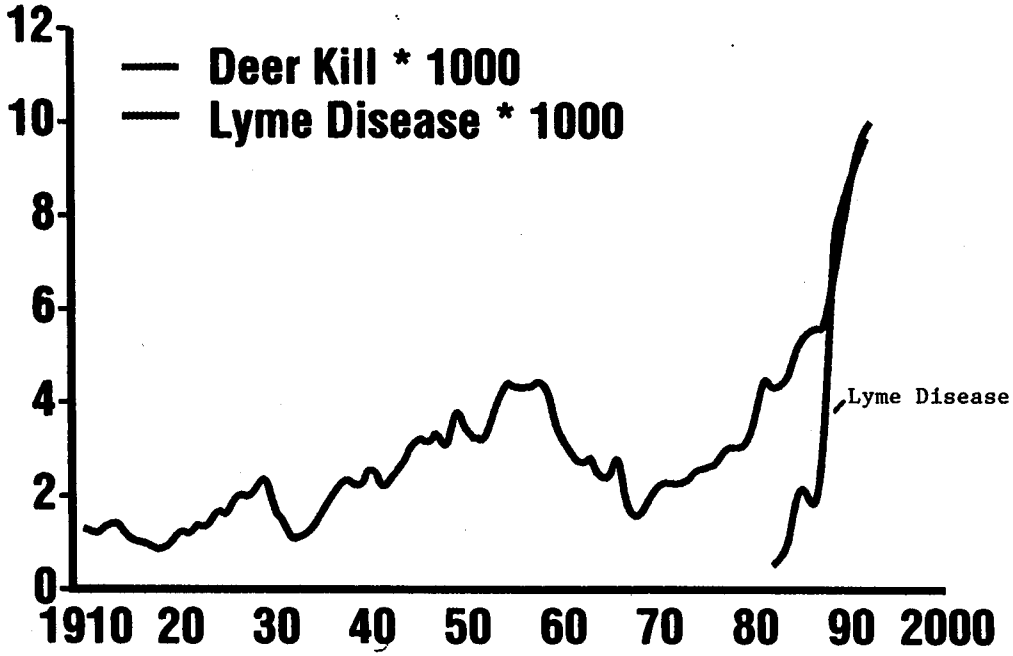


Figure 13. Comparison of Lyme Disease cases with the abundance of deer in Northeastern United States.

SUMMARY

Two examples are given where action makes sense because of the level of risk and the level of our vulnerability to natural variability as well as the potential for future climate change. In the face of uncertainties associated with the observed record and model predictions, we must adopt practical strategies for dealing with the potential impact of climate variability and change. These strategies should be based on two elements: (1) a strong observation and modeling research program within the U.S. designed to enhance economic vitality and national security, and (2) a litmus test for decision makers based on the level of risk and vulnerability to natural variability as well as future climate change. These two elements provide the most logical basis for policy decisions.

RESPONSES BY DR. ERIC BARRON TO ADDITIONAL QUESTIONS FROM SENATOR BAUCUS

Question 1. During the hearing, you stated that our strategies to address increasing concentrations of greenhouse gases should be adaptive in nature. In your opinion, what would be the most important adaptation strategies to pursue.

Response. Decisions concerning adaptation strategies should be based on assessments of risk and vulnerability that involve natural variability in climate as well as the prospect of future climate change. If society already exhibits vulnerability to natural variability, and the prospect of climate change due to increases in greenhouse gases may exacerbate that vulnerability, then the argument for adaptive strategies becomes stronger. In my opinion, the strongest arguments to pursue adaptive strategies because of climate and climate change are for water resource availability and water quality, severe weather hazards, and human health. The types of strategies to pursue for these three areas are illustrated by examples. First, we already have considerable problems with water resource availability associated with climate variability. Water quality also frequently depends on the dilution power of rivers and streams, and thus is dependent on water availability. The adaptive strategies for this problem are varied and range from protection of groundwater resources (e.g., controls on growth and development in local recharge regions), assessment of water use and priorities under different climate and climate variability scenarios, planned changes in storage facilities where demand already frequently exceeds supply, and efforts to promote greater water use efficiencies. Second, increases in severe weather, as a product of natural variability or human induced changes, would have a major impact on property and human life, and has the potential to dramatically change the insurance and re-insurance industry with an impact on economic growth (based on the number of billion dollar natural disasters during the last decade). This implies that we limit rebuilding, for example in disaster-prone coastal regions, or individuals should assume the risk. Third, the emergence and re-emergence of infectious diseases and the heat-elated mortality of the last decade are also suggestive of considerable vulnerability to climate and climate vulnerability. In this case, the adaptive strategies should involve such actions as disease surveillance, public education, and maintenance of health care and research facilities. Each of the above strategies has the potential to have positive impact on society regardless of whether human-induced global change becomes a major factor in the future.

Question 2. Dr. Schneider stated in his testimony that it was difficult for plants and animals to adapt to a temperature increase of 5°C over the 10,000 year period following the last Ice Age and that many species would likely go extinct with a kind of rap id temperature increase projected for the next century. Assuming, for the purpose of this question, that the Earth experiences a temperature increase of greater that 1.5°C over the coming 100 years, what is the likelihood that species will successfully adapt? If in your opinion, this represents a threat to preserving biological diversity, to your knowledge has there ever been a period in the paleoclimate record where climate change has resulted in significant loss of species?

Response. Largely because of changes in the land surface due to human activities we have already experienced, and will continue to experience, major changes in biological diversity. I suspect that this factor will continue to play the largest role in modifying biological diversity, while a climate change of 1.5°C would be a secondary factor. However, there are two issues to consider. First, a 1.5°C temperature change is in the global average. Some areas, notably higher latitudes and the continental interior regions of the mid-latitude continents, are likely to experience substantially greater temperature and water balance changes. Therefore, the vulnerabilities of species may be very different from region to region. Second, human land use may present a major issue in the migration and adaptation of different species to climate

change—in other words farms, cities and other human habitations may present considerable barriers to migration. Adaptation may then also depend on human actions and assistance. Given the importance of human land use in biological diversity, I suspect it would be very difficult to estimate how well species will adapt to climate change. There have been numerous abrupt changes in biological diversity during earth history, with multi-million year times for recovery of biological diversity and the development of numerous new species. The causes of such extinctions are a matter of considerable debate, but often climate change is included as one of theories offered to explain these events.

Question 3. Dr. Lindzen referred in his testimony to a natural mechanism that would be employed by the Earth to counteract the predicted climatic changes due to the effect of increased water vapor in the atmosphere. Are you aware of any historic reference or specific research that would support a theory of the existence of such a mechanism?

Response. Dr. Lindzen's argument has been seriously debated by the scientific community, with several research projects (particularly associated with research in the Pacific tropics) directed to test these ideas. To my knowledge, no conclusive proof that this mechanism exists has yet been offered and some evidence has been supplied which is negative. In my view, Dr. Lindzen's mechanism is far from acceptance, however, he has provided an important service in focusing attention on how poorly we currently measure water vapor in the upper troposphere and in the dry regions of our atmosphere. I believe that he is correct in recognizing that uncertainties in our observations in these regions produces uncertainties in climate model predictions.

Question 4. Dr. Lindzen stated in his testimony that one specific feature that led to the IPCC conclusion of a discernible human influence on global climate, ". . . disappears when additional data is considered." Are you aware of specific "additional data" that was not considered or erroneously applied that would cause the IPCC to reach a different conclusion? Are you aware of a specific research result or model that supports Dr. Lindzen's claim? If so, did you know whether the IPCC considered it? Are you aware of other factors that the IPCC relied upon to conclude that human activities were impacting global climate?

Response. I am unaware of any specific "additional data" that was not considered or erroneously applied that would cause the IPCC to reach a different conclusion. On the contrary, I do believe that the evidence is growing stronger. In my opinion, the IPCC assessment process is well-reasoned and broadly reflective of the weight of scientific opinion and evidence.

Question 5. Do you believe there is sufficient evidence of a problem with human-induced climate change for us to keep pursuing some kind of policy to limit CO_2 emissions? If not, should we stop funding research that would tend to prove or disprove the theories that human activities are impacting global climate? If there is sufficient evidence, what more, if anything, should we be doing?

Response. My answer to this question is based on several views. First, 1 think the best scientific evidence available supports the view that a 1.5 to 4°C increase in globally averaged temperature will occur with a CO_2 concentration doubling. In my view, a climate change of this magnitude will have severe consequences. Second, I believe that continued increase in atmospheric CO_2 concentrations are inevitable for many years to come because of the increase in world population, the abundance of fossil fuels like coal, and the push for higher standards of living in many developing countries. Regardless of U.S. actions, the global experiment in atmospheric chemistry will continue. Therefore, I personally believe that much of the climate change due to greater concentrations of greenhouse gases is inevitable unless the whole world takes action. Third, as the greatest per capita user of fossil fuels, I believe that concerted international efforts will not happen without the U.S. taking action first. The problem is that any action by the U.S. which might be publicly acceptable in our country is likely to be too small to impact climate change because of world fossil fuel use. The argument for emissions controls then becomes one of taking action for the purpose of promoting efficiency (a valuable effort in its own right) and providing the leadership necessary to begin a process of reduced global emissions. My feeling is that such steps have the potential to bring unexpected positive surprises, delays in the time of CO_2 doubling, and greater efficiencies with positive benefits, but that adaptive strategies are likely to be the major way we address greenhouse warming over the next 50 years.

Research remains critical for several reasons. First, I believe that observations and predictions, as they improve, will become increasingly valuable. They may minimize risk and vulnerability and they are likely to have positive economic value

given the importance of most "advance knowledge" in our society. Second, I believe that the ozone depletion problem and the greenhouse gas problem are just examples of what lies in store for the world population. Given the growth in population and the breakneck speed of technologic change, humans are ever more capable of impacting the nature of our environment. Greater knowledge of how the earth system works will become increasingly important for each generation, because our response time for providing solutions to problems may well get shorter as world population grows.

Question 6. In your professional opinion, what is the probability that there will be a doubling of CO_2 concentrations since pre-industrial times by the year 2100? A tripling? what are the impacts of a doubling? what are the impacts of a tripling?

Response. In my opinion, the probability that there will be a doubling of CO_2 concentrations by the year 2100 is very high, while the probability that there will be a tripling is much lower. The article submitted as part of my written testimony on the reliability of climate model predictions gives a precise account of my views of the most likely impact of a doubling of carbon dioxide. The impacts of a tripling of carbon dioxide are much less studied, but are likely to be similar to the impacts of a doubling, but of greater magnitude.

RESPONSES BY DR. ERIC BARRON TO ADDITIONAL QUESTIONS FROM SENATOR REID

Question 1. Much has been made of the newfound general consensus that there is a "discernible human influence on global climate." What exactly does this mean?

Response. Climate varies on many different time scales in response to many different factors (as a product of volcanic eruptions, or simply the way that the atmosphere and ocean interact). Changes in climate on the time scales of decades to centuries is therefore not at all unusual. At the same time we know that human activities, specifically the burning of fossil fuels, is increasing the level of greenhouse gases in our atmosphere and that this increase will cause a greater absorption of the energy being radiated to space from the earth's surface, thus promoting warming. Therefore, we have more than one factor operating which has the potential to influence our weather and climate—the so-called natural variability and the human-induced changes. We also know that the earth has experienced a global warming of .4 to .6°C over the last century. The question is one of attribution, is this warming a product of human activity or of natural variability. The consensus cited in the question means that the way climate has changed over the last century is suggestive of a warming due at least in part to the increases in greenhouse gases. Such a conclusion depends on evidence that the nature of the change is unlike the natural variations recorded in the past and that the changes have a "fingerprint" which matches the expected changes due to increased greenhouse gases.

Question 2. During the 1980's, we heard a lot about global warming. Now we are hearing a lot about global climate change. Are they the same thing? How are they different?

Response. The topic hasn't really changed, only the perspective. The nature of the climate changes associated with higher greenhouse gas concentrations involves much more than temperature changes (e.g., changes in precipitation, sea ice distribution, snow cover, etc.). Climate change incorporates a spectrum of factors that is greater than just temperature. Second, greenhouse gases are not the only human-induced changes. We are also changing the land surface dramatically and the amount of aerosols (fine particles) in the atmosphere. Each of these factors can influence climate. The term climate change is more comprehensive than the term global warming.

Question 3. Assuming for the moment that greenhouse gases are accumulating in the atmosphere, how long will it take to get them out? If we are not likely to face real problems for 20 to 40 years or more from now, is it really necessary to begin making reductions now? Would the Nation be better served by waiting for the technology and other efficiency improvements to develop further?

Response. Numerous studies have recently been undertaken to determine how long the greenhouse gases that are accumulating in the atmosphere will remain. Basically, the mechanisms for removal include the productivity of plants, the uptake by the ocean, and the weathering of rocks and minerals. Major increases in plant productivity would remove carbon dioxide, but such changes are not rapid. Uptake by the ocean, largely dependent on the sinking of water masses to depth is very slow—centuries to thousands of years, and rock weathering processes are even slower. Most studies suggest that if emissions were to stop today, many centuries would be required for the atmosphere to return to pre-industrial levels.

Scientific certainty over having some level of impact grows after the concentrations of CO_2 in the atmosphere approaches levels of a doubling, but this does not mean that we are necessarily unlikely to face real problems for 20 to 40 years. In terms of human health issues, water resource availability, water quality and weather-related natural hazards, we are already experiencing problems due to some combination of natural variability and human-induced climate change. However, as stated in my testimony, I believe that some climate change is inevitable even with reasonable plans for emission reductions because of the growth of world population and because the desire by many nations to increase their standard of living will cause CO_2 concentrations in the atmosphere to continue to rise. In my view, the efforts to control emissions are unlikely to make a marked impact of the climate of the next 50 years because, in themselves, they won't dent the level of global emissions. Rather, such emissions controls would serve to promote the technology and efficiency improvements that may lead to unexpected positive surprises, as well as provide needed U.S. leadership in the world.

Question 4. Germany and the United Kingdom seem to be the only nations that have made real progress toward achieving their voluntary emissions reductions goals. How did they do it and are there lessons in this for the United States?

Response. Although I am not a social scientist and have not studied the spectrum of factors in other countries which promote emission reductions, personal experience suggests that the higher prices for fuels in the U.K. and Germany, combined with their records of economic growth, are likely to be a reasonable explanation. Higher fuel prices certainly promote greater efficiency or conservation.

RESPONSES BY DR. ERIC BARRON TO ADDITIONAL QUESTIONS FROM SENATOR BOXER

Question 1. Are the effects of increased greenhouse gases reversible?

Response. The earth system has many different feedbacks, and if greenhouse gas emissions by humans were to be reduced substantially and concentrations in the atmosphere were to return to pre-industrial levels, the climate system would likely return to a state more similar to the pre-industrial level after many centuries. However, climate change is caused by many factors, including human-activities, and therefore it is unlikely that any future climate will be identical to the pre-industrial era.

Question 2. If we halt the increase in production of greenhouse gases, would temperatures continue to rise or would they remain steady?

Response. If the increase in greenhouse gas emissions were halted, then the concentration of greenhouse gases produced by humans would tend to stabilize, and then the climate "forcing" of these gases would tend to stabilize. Therefore the added tendency to promote warming would be removed. However, the response time of the atmosphere and ocean is not immediate, and the modem climate is unlikely to be in balance with the current level of carbon dioxide in the atmosphere. For this reason, I believe that it would still be a matter of decades before the majority of the climate change due to current CO_2 levels would be realized.

Question 3. In your opinion, should the lack of complete certainty regarding the science of climate change result in a wait-and-see approach?

Response. For many decades to come, there will remain substantial uncertainty about global change. The question facing society is a tough one. Climate models provide the best currently available assessment of future climate change, and these models suggest substantial change due to human greenhouse gas emissions, yet the models are associated with substantial uncertainty. In my view the solution to this conundrum must be to assess how vulnerable we are to climate change. Further, I believe that we are already vulnerable to natural climate variability, and climate change may exacerbate this vulnerability, and this is sufficient reason to take action. In many cases this action should involve adaptive strategies.

Question 4. We hear about natural climatic cycles. For example, we know from geologic evidence that the earth has naturally gone through cooling and warming cycles, usually on a scale of 10's of thousands of years. Is it possible to identify cycles of a shorter scale?

Response. Geologic evidence suggests that the earth experiences climate change on many different time scales from decades to millions of years.

Question 5. Would we be able to detect variations attributable to human activities in this natural cycle?

Response. It is not a simple task to attribute any climate change to human activities precisely because of the natural variations that occur. The key is to detect

changes which are unlike the spectrum of natural variations over the last several thousand years and to detect changes that "fingerprint" changes caused by a particular human-induced forcing factor, like increased concentrations of carbon dioxide in the atmosphere. Through model and laboratory studies we expect specific types of changes (e.g., cooling of the stratosphere at the same time the lower atmosphere warms). These lines of evidence are the reason why the IPCC report now states that some level of human-induced change is now detectable.

Question 6. We know that CO_2 has the potential for affecting the climatic balance of our atmosphere. Would it not make sense to limit the amount of CO_2 we put into the atmosphere until we more fully understand the effects CO_2 has on our atmosphere?

Response. Ideally, it makes perfect sense to limit the amount of CO_2 we put into the atmosphere until we have more knowledge. Unfortunately, carbon-based fuels are a critical underpinning of the world economy. To control emissions to the point of having a real impact on future climate change is likely to have major economic impact. However, actions that begin control emissions may well produce unexpected positive impacts on technology and efficiency that may help limit the long-term potential for large climate changes. In my opinion, over the next half century higher greenhouse concentrations are probably inevitable and some level of climate change is likely to occur despite efforts to control emissions.

Prepared Statement of John R. Christy, Department of Atmospheric Science and Earth System Science Laboratory, University of Alabama in Huntsville

1. CONCERN FOR CLIMATE CHANGE

In the 1980's, Global Warming due to the enhanced greenhouse effect came to be perceived as a serious threat to the planet's ecological and societal sustainability. This concern was based primarily on estimates of global warming and other climate changes from numerical models of the Earth's climate system. (This perception was reinforced by a few hot, dry summers in the eastern U.S. which constituted for some people the "smoking gun" of climate change.) While the development of models is critical to our future ability to examine what we may be doing to alter the climate of the Earth, many scientists acknowledge that models are still rather simple representations of the complex processes that control the Earth's climate.

The observational evidence for enhanced greenhouse global warming is also less than clearly defined. While all surface-based global temperature data sets indicated warming of 0.3 to 0.6°C since the last century, the complete source of this warming is still unknown. First, the Earth was evidently coming out of a relatively cold period in the 1800's so that warming in the past century may be part of this natural recovery. Data sparseness and reliability are somewhat suspect in the early years of the thermometer climate record and remain a concern even today when the shrinking network of stations is attempting to capture relatively small variations. Local land use changes may also have added additional warming not connected with greenhouse gases.

With this background, scientists recognized that we did not have an observing system in place with adequate means to truly monitor the health of the planet or to provide the data needed to validate and improve the models of the Earth System. One obvious limitation of information about the atmosphere was the lack of true global coverage.

2. THE MICROWAVE SOUNDING UNIT DATA SET

I am here to report a success story—a story that involves U.S. Government scientists and managers who collaborated closely and productively with university scientists. In 1989, to test the ability of satellites to monitor the Earth, Dr. Roy Spencer, a NASA scientist, and I began investigating temperatures measured by the existing TIROS–N family of weather satellites (average life span was only 4 years each). These satellites were designed to provide information for daily weather forecasts, not for answering questions about global climate change.

The instrument of interest to us was the Microwave Sounding Unit (MSU), identical copies of which were flown on all of NOAA's operational polar orbiters since 1979. The MSU measures the intensity of weak microwave radiation emitted to space by oxygen in the air. The magnitude of this intensity is proportional to air temperature, so with global coverage by the satellites we could compute the true globally averaged air temperature. Two specific layers have lent themselves to accurate measurements: (1) the lower troposphere, or the lowest 7 km of air next to the surface, and (2) the layer at 17–21 km, or lower stratosphere.

Putting together a climate record from multiple satellites involved collecting a huge volume of data and was a remarkable achievement in and of itself. It is a tribute to the current government system and the vision of scientists at the National Center for Atmospheric Research (NCAR) that those data (with little perceived market value at the time) were saved and archived. The MSU data products are now almost priceless in the global warming debate in having established a precise historical record of the Earth's temperature over the last 18+ years.

It was our good fortune that my call to NCAR asking about the possibility of obtaining the MSU data came 1 week before a previously scheduled, major NCAR project was to begin to copy all satellite data from an old, outdated storage system to a newer one. Thus, forewarned that Spencer and I believed the MSU data were of some unique value, NCAR kindly extracted the necessary data (only 2 percent of the total) for us at only the marginal cost of the extraction process. This relatively "free and open" attitude concerning data availability was the key to our success in creating the MSU data set, since obtaining the data from a cost-recovering data center would have been prohibitive (the quote was over $1 million) for the speculative value of the MSU data for climate monitoring.

The computing facilities for our own massive processing task were provided by NASA's Marshall Space Flight Center, and we had the enthusiastic support of the Earth Science and Applications Division. After several months of tedious data analysis, we were able to construct various data sets with exceptional precision and continuity. The particular technique we eventually developed allowed the MSU data to be independently validated. In Fig. 1, I show the comparison between MSU temperatures and those measured by radiosondes (balloons) in which a weather instrument package is carried aloft. These two systems (satellite and radiosonde) are completely independent in every way. In Fig. 1 it is clear that both systems are measuring the same variations in temperature to high precision.

For long term variations, I include in the table below comparisons between large numbers of radiosondes and MSU measurements. It is again clear that both systems are telling us the same story on temperature variations since 1979. Note that none of the long-term trends differ by more than ±0.03°C/decade.

Comparisons of trends since 1979 for MSU lower troposphere vs. various radiosonde-based tropospheric datasets which, except for the 850–300 hPa layer temperature, are weighted to match the MSU weighting function.

	No. stations used	Balloon Tr end °C/dec.	MSU Trend for same region	Difference (Balloon minus MSU)	Years
Global (850–300 hPa)[1] ..	63	−0.06	−0.04	−0.02	79–96
No. Hemisphere[2]	250+	+0.01	+0.02	−0.01	79–96
So. Hemisphere[2]	50+	−0.11	−0.08	−0.03	79–96
Global[2]	300+	−0.04	−0.04	0.00	79–96
W. No. Hemisphere[3]	97	+0.16	+0.14	+0.02	79–94

[1] Angell 1988 and updates.
[2] Parker et al. 1997.
[3] Stations in an area roughly bounded by Truk, South Pacific to Pt. Barrow, AK to Keflavik, Iceland to Trinidad. This is a comparison of sondes with colocated MSU.

Our datasets begin with January 1979 and continue to this day. We have been fortunate that two of the four MSU channels have performed exceptionally well on each of the nine satellites that were launched at intervals of about 2 years. It was critical that at least one satellite in functioning condition was orbiting when a new satellite was launched, because we required a period of overlap for precise intercalibration. (Only two satellites are operational at a given time).

3. THE TEMPERATURE OF THE LOWER ATMOSPHERE

The temperature of the global atmosphere is shown for the lower troposphere and lower stratosphere in Figure 2 (courtesy R. Spencer). Since we live in the lower troposphere, that time series has received the most attention. You will notice that there are large variations, both month-to-month and year-to-year. Because these variations are independently observed by two satellites, we know they are real. The trend in the time series is slightly downward (−0.05°C/decade or −0.09°F/decade). It is this relatively flat trend when compared to surface data (which show warming trends since 1979 of +0.09°C to +0.14°C/decade, depending on which dataset is cited) that has attracted attention to the Spencer/Christy MSU dataset.

Though the MSU temperature record has demonstrated high precision, there is also an element of ambiguity in the measurement. The layers measured by the MSU are several kilometers deep. Any intra-layer variability, therefore, would be masked by the vertical average. For example, a warming trend at upper levels and a cooling trend at low levels of one layer would be seen as no trend in the MSU vertical average.

One of the reasons the surface thermometer data have shown greater warming in the past 18 years is due to the fact that in continental regions the surface temperature responds with greater variation than the deep layer of air above. Over oceans (and in the global average), the opposite occurs. In the past 18 years there has been a tendency for the atmosphere over land areas to show warming (which is greater in the surface air response) while the atmosphere over oceans has exhibited cooling (greater effect in the MSU record). This pattern is thought to be due to natural variations. The net effect in the global average is a relative difference in the trends between surface air and the deep atmosphere. Thus, the uneven warming/cooling distribution of the past 18 years accounts for part of the difference.

Other differences are due to areas poorly sampled or not sampled at all by the surface network, as well as to some urban warming or land-use changes around many of the thermometers. It is a monumental achievement to construct a record of surface air temperatures, and most of these data sets have been subjected to many careful corrections to account for these non-natural temperature impacts.

Because of its precision and true global coverage, we believe that the MSU dataset is the most robust measurement we have of the Earth's bulk atmospheric temperature. At the same time, it is still a relatively short data set for climate studies. As indicated in Figure 2, the data contain both long and short period fluctuations. To be useful in the global warming debate one must understand and carefully account for fluctuations in the data that may be masking or dominating the anticipated enhanced greenhouse signal.

Recently, two colleagues have questioned the precision of the MSU data. They believe the data have spurious jumps in 1981 and 1991 which caused the overall trend to be downward rather than upward as they believe it should be. Their basis for this allegation utilized no observed data from the atmosphere. Since the time their allegations were made public I have shown that the MSU data are indeed precise with independent and direct observations of the troposphere (i.e. I used real data). For example, in the most serious allegation, my two colleagues speculated that the merging of one satellite, NOAA–7, into the time series caused a spurious 0.25°C jump in late 1981 in the tropical time series. I show in Fig. 3 the temperature anomalies of two satellites NOAA–6 and—7 for the tropics during that time. It is important to note that these are completely independently calculated. One can readily see that whether NOAA–7 was included or not, the time series is still the same. Therefore, the addition of NOAA–7 into the dataset did not cause a problem and the claim of my colleagues is clearly in error.

4. THE CAUSES OF THE TEMPERATURE VARIATIONS

In a recent study, Dr. Richard McNider, also of the University of Alabama in Huntsville, and I looked for the causes of the natural fluctuations. We found that by accounting for the influence of tropical ocean temperatures (El Niño) and the cooling effect of volcanoes, we could explain over 60 percent of the monthly variations (Fig. 4). These natural, shorter-term fluctuations indicate to us how much the global temperature responds to specific causes. Once calculated and removed, we see that without El Niños and volcanoes, the temperature trend of the past 18+ years is upward (+0.06°C/decade or +0.11°F/decade, Fig. 4, bottom. The value varies from +0.05 to +0.10°C/decade depending on certain parameters specified.). What is causing this upward trend? We do not know for sure. It may be the enhanced greenhouse effect. At the same time there could still be a longer term trend in the data due to variations in aerosols, water vapor, or other unknown factors that are masking the true magnitude of the greenhouse effect.

The latest results from global climate models, which include improvements and the cooling effects of air pollution, indicate warming rates for the Earth of +0.08°C to +0.30°C/decade for the latter part of the 20th century. These are about half of the warming rates predicted a few years ago, when only increases in greenhouse gases were modeled. Note too, that according to the latest models there should be more warming in the troposphere than at the surface. Therefore, the MSU is ideally suited to provide information on the layers that should show the greatest change. The present warming rate of +0.06°C/decade observed in the "adjusted" MSU data is just outside this model range, and is not inconsistent with fully natural variations

on decadal time scales. Therefore, uncertainty remains as to the cause(s) of the trend the MSU has measured.

Why is there a discrepancy between the models' estimate of global warming and what the MSU data have shown? One must remember that temperature is essentially a response parameter. The MSU data in Figure 2 show us what has been happening to the climate but not why. A key goal of efforts to study the planet from space is to provide heretofore unmeasured data that can provide an understanding of why the Earth system behaves as it does. I believe that new observables such as aerosols, rain structures, water vapor distributions and surface characteristics, when used in conjunction with the MSU data set will provide answers to these questions. Our work demonstrates that satellites can be used to monitor the Earth on decadal time scales and that the vantage point of space offers the only truly global view of the Earth system that can give robust measures of key variables.

The Spencer-Christy MSU data set has been used by some as evidence that global warming is not important, which then undercuts the need and urgency of programs to continue to study the Earth System. I strongly disagree with this interpretation. By showing that the Earth's rate of warming is slower than predicted by earlier models or surface data sets (Fig. 5), it does, perhaps, remove the sense of urgency for those who wish to enact greenhouse gas controls or to shut off scientific debate. But most importantly, the slower warming rate in the last two decades in effect gives us the security of time so that data from future observations and research may be used within the debate.

I believe that honest and open scientific debate with precise data is the key to making sound societal decisions. The cultivation of diversity of scientific thought is critical to vigorous debate. The MSU data set would not have been developed without the competitiveness and entrepreneurial spirit fostered by having separate NASA science centers and a broad university research program. Industry should recognize that good science and good data are their allies, whether in debates on acid rain or global warming. It is now more critical than ever that we study the planet's health with new diagnostic devices. Any delays in doing so may mean that the length of data records available to scientists will be reduced and cannot be used in the societal debates.

The disagreement between models and the MSU simply illustrates how little we understand about the complexities and factors that control the Earth's climate. Every month Roy Spencer and I process the newly arrived data and eagerly look at the month's temperature to see what is happening to the Earth. If we knew everything we needed to know about the Earth's system, we would not be as anxious about the results. I look forward to the time when new data from planned satellite sensors, coupled with an understanding of the Earth's climate system developed under research programs emphasizing global change, make surprises in the MSU global temperature as rare as being surprised by land-falling hurricanes in this era of weather satellites.

5. THE TEMPERATURE OF THE LOWER STRATOSPHERE

The record of the lower stratosphere is fascinating in its own right. Clearly, here is an example of global change on the scale of years to decades (Figure 2). The two conspicuous warming events were due to explosive volcanic eruptions—El Chichon (1982) and Mt. Pinatubo (1991). The aerosols injected by these explosions high into the stratosphere caused the warming through radiative interactions. Notice, however, that once the aerosols settled out, the global stratospheric temperature fell to levels below those observed at pre-eruption. It is widely thought that the loss of stratospheric ozone, both naturally from volcanic events and from human-generated chemicals, has caused this overall cooling. The increase in greenhouse gases, which will cause stratospheric cooling, is probably a factor as well, though smaller.

The 1996 annual stratospheric temperature was the lowest annual value ever measured by satellite, and March 1997, was the coldest single month on record for the North Polar region. (Globally, the temperatures have rebounded a bit for the first half of 1997.) Something is changing in the lower stratosphere—the temperature tells us that much, but cannot specifically indicate the cause. (Others have much more experience here.) The extent of the stratospheric cooling trend points to the need to fully understand its cause.

6. CONCLUDING REMARKS

Continued monitoring of global temperature through the Spencer-Christy method is expected as long as our good fortune holds and the two orbiting instruments do not fail (which almost happened recently). Thus, we should continue to provide the scientific community with precise temperatures for deep atmospheric layers.

In any weather variable, e.g., temperature, rainfall, etc., it is the shorter-term fluctuations (week-to-week) that cause the greatest impact on human productivity. One valuable benefit of a program of escalating Earth observations is the resulting improvement in weather forecasts—particularly out to 2 to 3 weeks and even to seasonal averages. The potential economic impact of improved long-range forecasts would be enormous. Virtually every sector of our economy is sensitive to weather, especially those related to energy production and consumption, agriculture, transportation, insurance and recreation. Improved knowledge of coming weather situations would be used to add value to the products and services generated by these industries.

A strong and continuing program in atmospheric observation and research has this more subtle benefit as well. There will be extreme climate events in the near future because that is the nature of weather and climate. Without a continuing program of research that places climate variations in proper perspective and reports with improving confidence on their causes, we will be vulnerable to calls for knee-jerk remedies to combat "climate change," which likely will be unproductive and economically damaging. We can protect ourselves from such pitfalls by improving our ability to measure what the climate is doing and determine the causes for its variations.

In simple terms, the "Global Climate" is our patient. We have taken its temperature in a few places and have seen just enough change to cause concern. Before prescribing any powerful medicine though, the patient should be given a complete physical as soon as possible, so we may then make the proper diagnosis and chart a correct course of action for the benefit of all.

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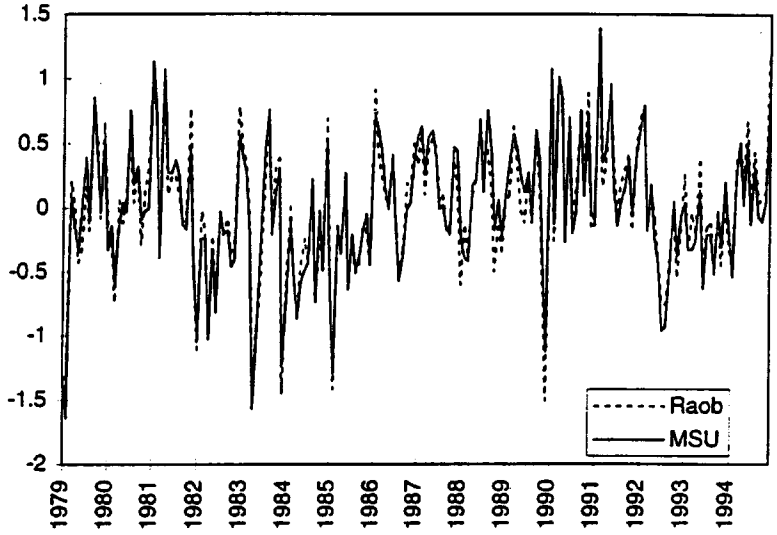
Figure 1: Independent validation of MSU temperatures

Average Monthly Anomalies 97 radiosonde stations and MSU 2R in W. No. Hemisphere



Decadal Trends:
Radiosondes +0.16°C, MSU 2R +0.14°C

Annual Correlation +0.97

Monthly departures from average for 97 radiosonde (balloon) stations and the MSU lower tropospheric temperature at 97 locations. These locations varied from the tropics to the Arctic. Excellent agreement between these two independent measurements validate the high confidence one may have in the MSU data.

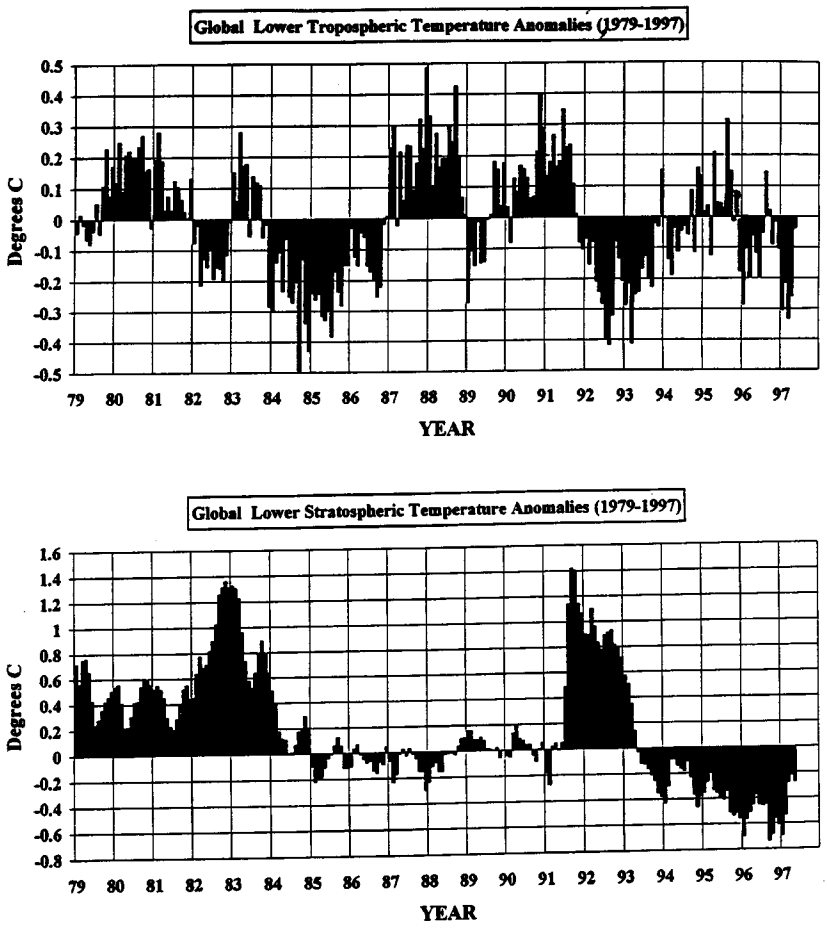
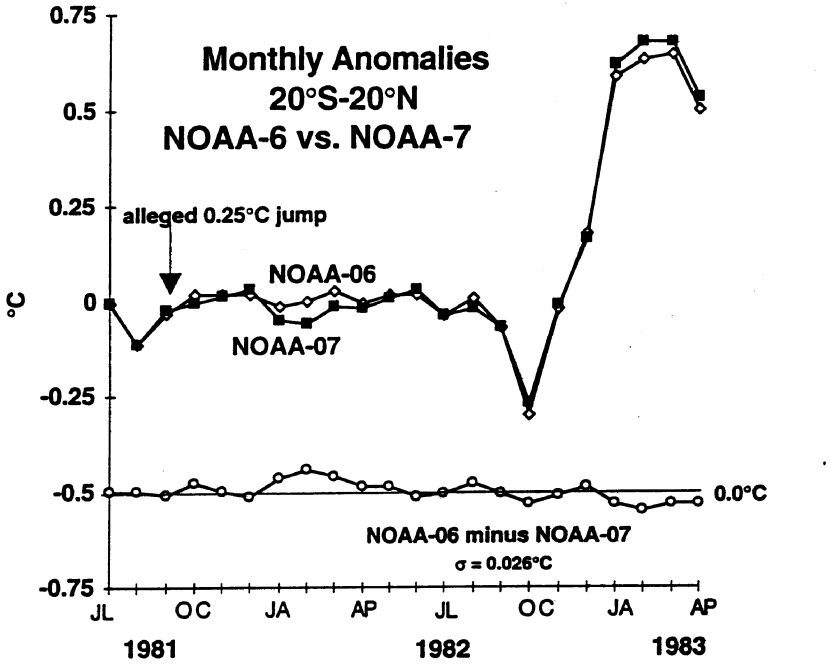


Figure 2. (Top) Seasonally adjusted monthly variations of the global temperature of the lower troposphere (surface to 20,000 ft.) as measured by Microwave Sounding Units. (Bottom) As above but for the lower stratosphere (50,000 to 65,000 ft.).

Figure 3 Two independent satellites observe the same temperatures in the tropics



Monthly temperature anomalies (°C) for the tropics (20°S-20°N) computed independently from two satellites, NOAA-6 and NOAA-7 for July 1981 to April 1983. The remarkable agreement disproves the claim that NOAA-7 caused a spurious impact on the temperatures.

John R. Christy, University of Alabama in Huntsville

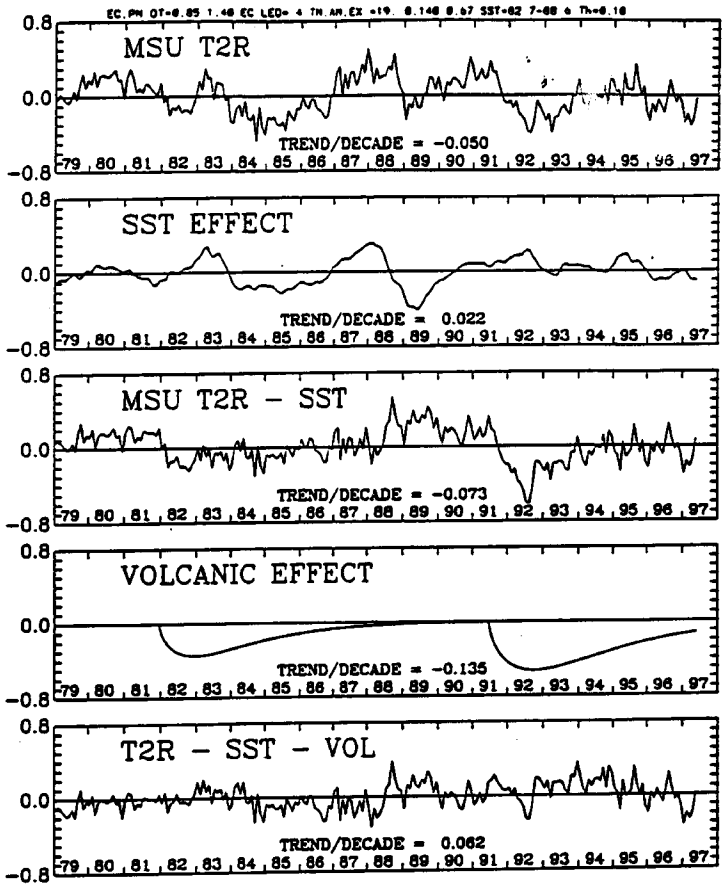
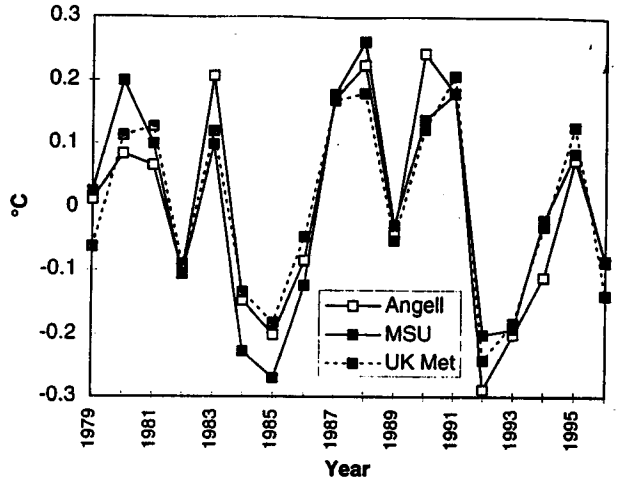


Figure 4. (Top). Monthly global average temperature anomalies (as in Fig. 2) for the lower troposphere (°C). (Second) The influence of tropical ocean temperatures on the global temperature. (Third) The global temperature after the influence of ocean temperatures has been removed. (Fourth) Influence on global temperature of volcanic events. (Fifth) Global temperature variation once Ocean and Volcanic effects have been removed.

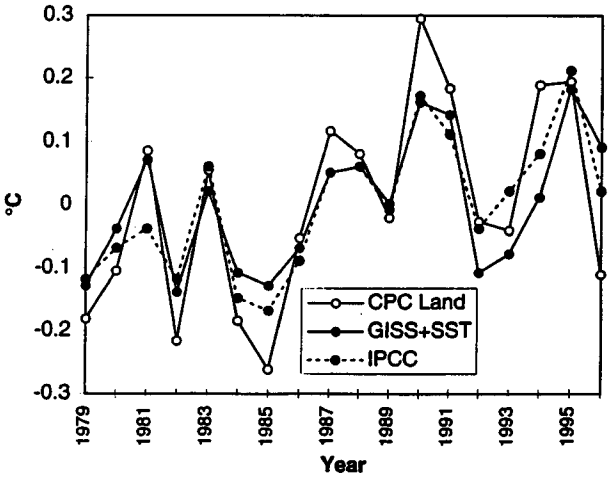
Figure 5
Global Annual Tropospheric Temperatures



Trends °C/Decade

Angell -0.05
MSU -0.04
UK Met -0.04

Global Annual Surface Temperatures



Trends °C/Decade

CPC Land +0.14
GISS+SST +0.09
IPCC +0.13

RESPONSES BY JOHN R. CHRISTY TO ADDITIONAL QUESTIONS FROM SENATOR BAUCUS

Question 1. During the hearing, Dr. Barron stated that our strategies to address increasing concentrations of greenhouse gasses should be adaptive in nature. In your opinion, what would be the most important adaptation strategies to pursue?

Response. In my opinion, preparing an economy to cope with the full range of natural weather variations (that will always occur) would position society to accommodate any future climate change better than simply adapting to a change after it occurs. For example, building a typical structure on beach front property along the Gulf and Atlantic coasts is not preparing for the full range of natural weather extremes because eventually a powerful hurricane will come along and devastate the region. However, development of cereal crops that can withstand greater extremes while enjoying higher CO_2 concentrations is an obvious avenue to pursue. (I use the term extremes not to imply that the future climate will have greater extremes, but that the crop could withstand whatever might come along.) We are a most adaptive and clever species, for example, being able to grow a single food (corn) in climates ranging from North Dakota to Alabama.

In an odd sort of way, conservation of carbon is actually one adaptive strategy because it is possible that the climate may cool in the next century or so. A colder climate is probably far more devastating than a warmer climate. Thus having carbon available for energy production in such a climate would be wise. An adaptive strategy is one that decreases our vulnerability to extreme events of all types.

As the IPCC has shown we still cannot identify regional weather changes due to CO_2 increases after over 100 years. And, in my view, it will be many more decades before the regional signal may (if ever) be extracted from the noise of natural variability. If present infrastructures could be designed to cope with 99.9 percent of the extremes on both sides (hottest, coldest, wettest, driest, etc.) rather than the 90–95 percent as is done now, we will be in much better position to handle what may happen in terms of climate change.

Question 2. Dr. Schneider stated in his testimony that it was difficult for plants and animals to adapt to a temperature increase of 50°C over the 10,000 year period following the last Ice Age and that many species would likely go extinct with a kind of rapid temperature increase projected for the next century. Assuming, for this question, that the Earth experiences a temperature increase of greater than 1.50°C over the coming 100 years, what is the likelihood that species will successfully adapt? If, in your opinion, this represents a threat to preserving biological diversity, to your knowledge has there every been a period in the paleoclimate record where climate change has resulted in significant loss of species.

Response. The significant loss of species has always been a feature of the history of the planet. I understand that approximately 99 percent of all species which have inhabited the Earth are extinct. Nature has been unmercifully severe for the vast majority of life forms. It is difficult to separate out the role of climate as a cause for extinction in comparison with other factors such as the evolution of competing and opportunistic species or something as exotic but as realistic as an asteroid collision.

Changes in global average temperature do not cause the loss of species, rather it is the local change of climate. The greatest rise in temperature due to the enhanced greenhouse effect (whatever its magnitude) is predicted to occur for those regions which already experience significant year to year and decade to decade variations (midlatitude and polar regions). I think we shall find that nature is rather resilient, though no one would expect the exact geographic distribution of populations of various species to remain identical to the present day. Perfect stability has never happened before. For example, the Southeastern quad rant of the U.S. has experienced cooling temperatures over the past 100 years with an associated southward displacement of plant species. am told that citrus crops were harvested as far north as southern Georgia around the turn of the century, yet today they are found commercially only from central Florida southward. This is due to the significant cold weather that the region has experienced in the last few decades.

Rapid, natural changes have occurred in the past. Let me quote from an issue of PAGES (Past Global Changes Programme, IGBP, 4, #3 Nov. 1996).

> Climate variability at both a regional and a global scale has, even within the boundary conditions prevailing during the Late-Holocene [last 5,000 years], been significantly greater than has been recorded during the short, recent period for which instrumental records of climate variation exist. This is conclusively demonstrated by recent research, is of crucial significance for predicting future climate change and is not recognized in the recent IPCC Report.

Since rapid changes have occurred in the past, we may assume that not every species survived the change. However, the species we see today must have survived some combination of past rapid changes. One wonders how many of today's species are actually here because a particular rapid change altered the balance between competing species in the favor of the present-day survivor. The system of life is exceedingly complex, and attributing climate changes to particular species survival is beyond my expertise.

I believe Dr. Schneider would agree that the number of species which might experience extinction due to possible global warming is much smaller than those we are losing today due to land-use changes, poaching, human encroachment, etc. Just as the evolution and redistribution of opportunistic species forced vulnerable species into extinction in the past, we are seeing human-induced extinction happening quite apart from climate change. We as a species are now one of those very opportunistic species that is dangerous to many others. If extinction is a concern, (and I believe it is) one should assess the major causes and then address those with action that has the best chance for producing results. However, I understand, having lived in a Third World country, that it is a difficult problem to advise other countries on this topic because (1) our own past haunts us and (2) the idea of loss of sovereignty is keenly felt in any nation.

I lived in Kenya, East Africa for 2 years and lived among people who were making decisions to destroy forests so they could raise food to feed their families. I could understand their motivation for survival as I witnessed people dying simply because they had no food. The population growth in that region, believe, is the cause of tremendous suffering and is the primary issue that must be dealt with ahead of the issue of climate change (if there is a choice on where to concentrate efforts). Of course, controlling population will probably have an eventual benefit of lower fossil fuel consumption.

I suspect I agree with Dr. Schneider in this limited sense: a significant fraction of the biosystem, relying only on evolution and redistribution, would find it difficult to adapt to a changing environment if the change occurred over time scales of centuries when research indicates biosystem changes normally take millennia to adapt.

Question 3. Dr. Lindzen referred in his testimony to a natural mechanism that would be employed by the Earth to counteract the predicted climatic changes due to the effect of increased water vapor in the atmosphere. Are you aware of any historic reference or specific research that would support a theory of the existence of such a mechanism?

Response. Global climate models produce most of their warming because they cause the troposphere (surface to 10 km altitude) to become more moist than is presently observed. In other words, global warming in the models is due more to additional water vapor than additional CO_2 in the atmosphere. This additional water vapor enhances the natural greenhouse gas, trapping more radiant energy in the lower atmosphere thus causing the surface temperature to rise even further. Models are quite primitive in the "rules" or equations they require the atmosphere to obey. In the case of greenhouse warming, the models require that as soon as the temperature rises a little due to CO_2 radiative forcing, more water vapor is forced into the troposphere, thus causing a "positive feedback" process: higher temperatures lead to more evaporation which leads to more water vapor in the atmosphere which leads to higher temperatures which leads to more evaporation, etc.

The real atmosphere does not appear to be so inflexible. Current research carried out by my colleague Dr. Roy Spencer of NASA/Marshall Space Flight Center (Huntsville, AL), points to the possibility that as the tropical system warms, the amount of vapor might actually decrease (or at least not increase much) in the troposphere. There are certainly periods (months or so, see Sun and Held, J. Climate 1996, pp. 665–675) in which warming is not accompanied by the presence of more water vapor as inflexible models require. The current warm El Niño event in the Pacific will be an excellent test case to check whether the tropical troposphere actually moistens or dries as the temperature rises. Currently, models give one result: the atmosphere always moistens when it is warmed.

The key mechanism to understand on this issue is that the heat that is naturally lost to space is highly proportional to the amount of vapor in the troposphere. Thus, the amount of water vapor in the troposphere regulates the amount of heat that escapes and which therefore would be unavailable to warm the surface. In fact, the vapor in the troposphere is more important for this energy balance than the vapor at the surface. A slight reduction of the vapor in the troposphere (i.e. a drying) leads to a significant increase in the outgoing energy. So, if there is a slight drying of the troposphere as the world warms a little, the drier troposphere would act as an open window to let more energy escape, thus reducing any feedback-warming of the sur-

face. Only slight changes in the tropical tropospheric humidity are necessary to reduce the warming due to the enhanced greenhouse effect. (The drying results from the fact warmer rain-clouds tend to lose more moisture to rainfall than cooler cloud systems, thus expelling less vapor to the troposphere.)

Considerable work is ahead of us on this area of research as theory is only now being given observations that may help solve this issue of tropospheric water vapor feedback. What we lack at this point is high vertical resolution observations of temperature, winds, precipitation and humidity of the extensive tropical atmosphere where so many questions remain.

Question 4. Dr. Lindzen stated in his testimony that the one specific feature that led to the IPCC conclusion of a discernible human influence on global climate, ". . . disappears when additional data is considered." Are you aware of specific "additional data" that was not considered or erroneously applied that would cause the IPCC to read a different conclusion? Are you aware of a specific research result or model that supports Dr. Lindzen's claim? If so, did you know whether the IPCC considered it? Are you aware of other factors that the IPCC relied upon to conclude that human activities were impacting global climate?

Response. A paper had been submitted just before the final IPCC science authors' meeting in Asheville, NC (Aug. 1995) which compared upper air balloon data for 1964 to 1987 and climate model results for the same period. The point of the paper was to show that the warming in the observations of the troposphere was matched by model results, thus the model was in some sense verified. I read the pre-publication paper at this meeting.

I discussed a bit of this paper with one of the authors at the meeting, pointing out that the early years were relatively cool in this 24-year period and the hottest year observed happened to be the last year, 1987. Thus, the period selected for the model comparison did not represent the actual climate variations for the longer period using pre-1964 and post-1987 data, and for which the model results had less agreement. The post-1987 data, showing cooling, were available to some researchers as I had submitted a paper 2 years before (1993) using data from this dataset which at that time were available through 1989. However, it could be the case that these post-1987 data may not have been in a form usable to the authors.

In Asheville, the author told me that he did not have available to him the post-1987 data and that a follow-up study would be completed in which such data would be utilized. I did not feel the author had deliberately stopped at 1987 to produce a "politically correct" result and in my other dealings with the author found him to be highly objective and credible. Utilizing the more recent data, however, the model in question apparently does not reproduce the observations nearly so well, especially the tropospheric non-warming that has occurred in the past 18 years (see Michaels, P.J. and P.C. Knappenberger, 1996: Sensitivity to the greenhouse fingerprint to data selection. Nature, 383, 12 December). Thus, the "discernible human influence" phrase may be viewed as only slightly less strong.

The main lines of evidence used to substantiate the "discernible human influence" statement as outlined in the policymakers summary were:

1. The 20th century appears to be the warmest of the past 600 years.
2. Several models, using only natural factors, could not explain all of the 20th century warming, thus implying that some fraction of the warming was probably due to human factors.
3. The vertical patterns of change produced by models which include human-factors match observed patterns of change for 1964–87.

The first statement is not as convincing as it seems because the data we examined (I was a key contributor to the IPCC)—and which were then used by the authors of the Policymakers Summary—were quite sparse before 1400. We all knew, and stated such in the scientific text, that the warming of the 20th century could largely be related to the natural "recovery" from the Little Ice Age, a cold period which existed, more or less, in the 15th–19th centuries. Had we used the sparse data prior to 1400, we would have reported that in many places on the planet, the decades around 1000 A.D. were warmer than even today. In the next IPCC report, this issue will probably be addressed in greater detail. What caused the earth to cool in the last six centuries is a topic of intense scientific research and it highlights the lack of understanding we now posses in explaining natural variations in the global climate.

The second statement comes from several model simulations of the last 100 years. These particular models could not reproduce all of the 0.40°C temperature rise of the last century unless they included the human factor of CO_2 forcing. We know, however, that the models are primitive and are essentially unable to reproduce other natural variations (e.g., Barnett et al., 1996; Estimates of low frequency natu-

ral variability in near-surface air temperature. Holocene, 6, 255–263). Barnett et al. concluded:

> . . . our results should serve as a warning to those anxious rigorously to pursue the detection of anthropogenic effects in observed climate data: the spectrum of natural variability against which detection claims, positive or negative, are made is not well known and apparently not well represented in early CGCM [coupled global climate model] control runs.

As I testified before the committee I agree with this second statement that some fraction of the observed 0.40°C warming is probably due to human factors.

The third statement relates to the paper I discussed earlier. I should add that a source of the relatively high correlation between the model and the observations was due to the strong cooling of the stratosphere found in the model results and in the observations. The main cause of this cooling is most likely ozone depletion, not CO_2. Thus, the CO_2 effects were less involved in the "match" with observations than was generally perceived by the public.

Question 5. Do you believe there is sufficient evidence of a problem with human-induced climate change for us to keep pursuing some kind of policy to limit CO_2 emissions? If not, should we stop funding research that would tend to prove or disprove the theories that human activities are impacting global climate. If there is sufficient evidence, what more, if anything, should we be doing.

Response. There are many severe human-induced environmental issues that I believe strongly overshadow the potential effects of global warming. Dealing with these serious issues would, I believe, lead to an associated reduction in CO_2 emissions. Population increases, habitat destruction, uncontrolled pollution of air and water by toxic emissions and effluent (not CO_2) are problematic now.

I believe we should continue supporting observations and research of the global system. Some observations are now being scaled back, and this reduces the base from which detection of any changes may be substantiated. Better observations combined with more research has the added advantage that forecasts, particularly extended-range forecasts, would likely be more accurate. This would allow the public to plan for weather impacts thus increasing their economic viability.

I can only comment as a non-expert in the realm of economic and social consequences of legislative actions intended to deal with climate change. What should we do? An idea I would put forth is to let the U.S. Government take the lead in generating reductions of CO_2. The government owns thousands of vehicles, electricity-intensive appliances, heavy equipment, inefficient buildings etc. By setting for itself more stringent standards, and purchasing new equipment and services within the free market, the government in effect sponsors the R&D for these new products, allowing future costs for these more efficient technologies to be lower to the public and therefore more acceptable in the long run.

Such a large government program must begin with accurate data on current emissions against which future reductions could be precisely assessed. I would think every aspect of government use of CO_2 would be measured (i.e. field tested) and documented. Then, a program to upgrade current vehicles, appliances, building environments, and even military maneuvers, to reduce carbon emissions could be instigated. The monitoring program would then be in place to prove to the interested parties (i.e. international monitoring agencies and the American public) that reduction in emissions is occurring. The government then would become the laboratory out of which proven technologies could be made available for the public, though some form of incentives would likely be required to replace cheap but inefficient equipment.

How would this program be paid for? My personal opinion is that a nickel tax per gallon of gasoline (i.e. "A Nickel for Nature"?) would not cause great hardship for the vast majority of Americans and would raise quite a bit of revenue for the government to proceed. Such a tax might even be politically acceptable if promoted as a way for everyone to help the environment and which is used entirely for its intended purpose.

It is important to remember that modest reductions in CO_2 will have an indiscernible effect on climate no matter what scenario of warming one may believe. Yet, I suspect modest controls are all that the public will accept.

Question 6. In your professional opinion, what is the probability that there will be a doubling of CO_2 concentrations since pre-industrial times by the year 2100? A tripling? What are the impacts of a doubling? What are the impacts of a tripling?

Response. Thank you for asking this question as an "opinion" as I do not perform research specifically related to the magnitude of CO_2 concentrations. I can only read the information available, and the IPCC reports are my main source of information.

The rise in CO_2 since 1958 has been slightly more than 1 ppmv per year, and most recently growth has been at a rate of 0.4 percent per year. The preindustrial concentration was about 280 ppmv, with today's value about 360 ppmv. By 2100, at this rate, the concentration would be between two and three times the preindustrial level. I believe there are factors yet unmodeled that will produce only a doubling by 2100. This is strictly an opinion based on my view that uncertainties are considerable in the present models and the economic and industrial future is rarely predicted with accuracy.

My opinion (and that is all it is) on the climate effects of doubling or tripling is that the effects will be fairly benign overall. If warming occurs, it will occur slowly and modestly. I will mention again that the effects of natural variability will continue to cause the havoc we have always known.

I would be remiss if I did not address a major aspect of this entire debate that has been basically ignored. It is popular today to think that burning carbon is an evil and destructive activity. I've lived in a Third World country, teaching physics and chemistry and sometimes distributing food and medicine to people in great need. These Africans were not nameless images on a TV screen to me, I knew them as fellow human beings with names, families, friends and hope. We provided for them that which they could not provide for themselves. What we gave came from an American nation whose economic engine has fueled the discoveries that have given our country a standard of living envied throughout the world and whose benefits have lifted many millions of non-Americans to a better life. I had a small part in that enterprise because American people, who burn carbon, were generous in financing experiences such as mine in Africa.

Today, the world's one and only superpower is dedicated to, among other noble pursuits, free and open scientific inquiry, freedom of faith and freedom of association. Such noble ideas are not expressed in the economic models out of which various scenarios of future policy are determined. What is their value? say they are invaluable. To be sure, we have "spent" considerable amounts of carbon to achieve what we have, but I believe it has largely been well-spent when one looks at the entire picture.

I realize that reductions of CO_2 are eventually going to affect us, yet I wonder if those who advocate draconian measures truly understand how the world as a whole would be affected. I've lived in a part of the world for which a loss of American economic strength and world leadership would probably cause greater suffering. As poorly as we model the global climate, even these physical results are more realistic than predictions of economic and social impacts which buildupon the imperfect climate model output. In short, the impacts to human existence of a doubling or tripling of CO_2 are almost impossible to predict when one considers our present level of ignorance in these matters.

Question 7. Dr. Christy, if you add balloon temperature measurement records to the 18 years of satellite temperature records, is there an observable warming trend? How does that compare with the surface temperature records.

Response. As I reported in the Hearing, the global balloon and satellite record both show that the lower tropospheric temperature has declined by—0.040°C/decade since 1979. Two years ago I wrote a paper which specifically addressed the comparison of various records of upper air temperatures for the period since 1958 when balloon datasets began: Temperature above the surface layer, Climatic Change, 31, 455–474, (1995). I found that "Beginning in earlier years, (relying only on radiosonde data before 1979) the estimated warming trend since the late 1950's is +0.07 to +0.110°C per decade." One surface dataset (GISS) shows a trend for the same period of +0.090°C/decade, which indicates that over this particular time period (1958–96), the surface and troposphere experienced the same trend. It is important to note that climate models project greater warming in the troposphere on all time scales, a feature which has apparently not appeared in the actual observations, and certainly is not verified in the observations since 1979.

RESPONSES BY JOHN R. CHRISTY TO ADDITIONAL QUESTIONS FROM SENATOR BOXER

Question 1. We hear about natural climatic cycles. For example, we know from geologic evidence that the earth has naturally gone through cooling and warming cycles, usually on a scale of 10's of thousands of years.

Is it possible to identify cycles of a shorter scale?

Response. Variability of global and regional temperature occurs on all time scales from minutes to millennia. Some of this variability occurs in a true cyclic fashion, for example, seasonal changes of temperature in which summer is warmer than winter or daily cycles in which afternoons are warmer than mornings. These two

examples represent the only regular cycles that can be identified. understand the comment "We hear about natural climatic cycles" because I hear it quite often too. However, as one who has poured over many records in detail, these alleged cycles are not as apparent as one would be led to believe.

Natural temperature variations due to El Niños, volcanoes, or fluctuations in solar radiation, atmospheric aerosol loading, oceanic circulations etc., are sometimes referred to as cycles, but they are much less predictable than forecasting that the temperature will be warmer in July than January. These other variations would not be categorized as strictly cyclic because they do not repeat with regularity.

Part of the problem here is that we are limited by the length and quality of our data records. If we accept the "global" surface temperatures for the past 100 years as having reasonable accuracy, even they cannot tell us whether variations on 200, 500 or 1,000 year time scales are occurring. Until we understand the magnitude and cause for these longer variations, we will be unable to state with any confidence that a human-induced global warming signal has been detected (unless the world suddenly begins to warm at a very rapid rate). The present rate of temperature change is not outside of natural rates observed in the past. The IPCC was careful to remind the readers in the Policymakers Summary that natural variability was a key uncertainty in this scientific endeavor and was a major reason for the cautious words ". . . balance of evidence suggests . . .".

Further studies of the paleoclimate records will lead to a more knowledgeable assessment of the scale of natural variations, and therefore provide the context in which detection of human-induced changes may be identified.

Question 2. Would we be able to detect variations attributable to human activities in this natural cycle?

Response. We know that climate models, which try to detect natural vs. unnatural changes, are primitive and are essentially unable to reproduce natural variations on the longer time scales (e.g., Barnett et al., 1996; Estimates of low frequency natural variability in near-surface air temperature. Holocene, 6, 255–263). Barnett et al. concluded

> . . . our results should serve as a warning to those anxious rigorously to pursue the detection of anthropogenic effects in observed climate data: the spectrum of natural variability against which detection claims, positive or negative, are made is not well known and apparently not well represented in early CGCM [coupled global climate model] control runs.

Thus, separating a slow, modest human-induced warming trend which is apparently smaller than changes observed in paleoclimate records, is a tenuous exercise at present. The problem here is that even more rapid, natural changes have occurred in the past. Let me quote from an issue of PAGES (Past Global Changes Programme, IGBP, 4, #3 Nov. 1996).

> Climate variability at both a regional and a global scale has, even within the boundary conditions prevailing during the Late-Holocene [last 5000 years], been significantly greater than has been recorded during the short, recent period for which instrumental records of climate variation exist [last 100 years]. This is conclusively demonstrated by recent research, is of crucial significance for predicting future climate change and is not recognized in the recent IPCC Report.

I prefer the terminology "natural variations" vs. "natural cycles" since the longer term variations are not strictly cyclic. I believe future research will continue to show that some of the past, natural changes were quite rapid and severe and that changes naturally occur from any century to the next. This confounds ones attempts to attribute any variation to human-effects. So, the short answer to this question is that unless the warming is dramatic (which to date it has not been), we will be hard pressed to prove that the present level of climate variation is due to human-induced causes.

Question 3. We know that CO_2 has the potential for affecting the climatic balance of our atmosphere. Would it not make sense to limit the amount of CO_2 we put into the atmosphere until we more fully understand the effects CO_2 have on our climate. If the consequences of choosing "limitations on CO_2" vs. "unlimited CO_2" were similar, I would readily agree that "limitations on CO_2" should be chosen. In the real world, however, forcing a limit on CO_2 production has tremendous economic (and thus, political) consequences. As we noted in the hearing, small or even moderate reductions in CO_2 production in the U.S. will do essentially nothing to change any possible global warming.

Response. An idea I would put forth is to let the U.S. Government take the lead in generating reductions of CO_2. The government owns thousands of vehicles, elec-

tricity-intensive appliances, heavy equipment, inefficient buildings etc. By setting for itself more stringent standards, and purchasing new equipment and services within the free market, the government in effect sponsors the R&D for these new products, allowing future costs for these more efficient technologies to be lower to the public and therefore more acceptable in the long run.

Such a large government program must begin with accurate data of the current emissions so that future reductions could be precisely assessed. I would think every aspect of government use of CO_2 would be measured (i.e. field tested) and documented. Then, a program to upgrade current vehicles, appliances, building environments, and even military maneuvers, to reduce carbon emissions could be initiated. The monitoring program would then be in place to prove to the interested parties (i.e. international monitoring agencies and the American public) that reduction in emissions is occurring.

In this scheme, the government would become the laboratory out of which proven technologies could be made available for public consumption, though some form of incentives would likely be required to replace cheap but inefficient equipment. How would this program be paid for? My personal opinion is that a nickel tax per gallon of gasoline (i.e. "A Nickel for Nature"?) would not cause great hardship for the vast majority of Americans and would raise quite a bit of revenue for the government to proceed. Such a tax might even be politically acceptable if promoted as a way for everyone to help the environment and the revenues were explicitly used for that program.

I suppose my point here is this: there are some rather modest programs that may be initiated to deal with what appears at this time to be at most a modest problem. These programs would have a minuscule effect of CO_2 concentrations, but would perhaps nudge a new set of technologies out into the market place due to the fact the U.S. Government is a very, very big customer.

I would be remiss if I did not address a major aspect of this entire debate that has been basically ignored. It is popular today to think that burning carbon is an evil and destructive activity. I lived in Kenya, East Africa for 2 years, teaching physics and chemistry and sometimes distributing food and medicine to people in great need. To me, these Africans were not nameless images on a TV screen. I knew them as fellow human beings with names, families, friends and hopes. We provided for them that which they could not provide for themselves. What we gave them came from an American nation whose economic engine has fueled the discoveries that have given our country a standard of living envied throughout the world and whose shared-benefits have lifted many millions of non-Americans to a better life. I had a small part in that enterprise because American people, who admittedly burn a lot of carbon, were generous in financing experiences such as mine in Africa.

Today, the world's one and only superpower is dedicated to, among other noble pursuits, free and open scientific inquiry, freedom of faith and freedom of association. Such noble ideas are not expressed in the economic models out of which various scenarios of future policy are determined. What is their value? say they are invaluable. To be sure, we have "spent" considerable amounts of carbon to achieve what we have, but I believe it has largely been well-spent when one looks at the entire picture.

I realize that reductions of CO_2 are eventually going to affect us, yet I wonder if those who advocate draconian measures truly understand how the world as a whole would be affected. I've lived in a part of the world for which a loss of American economic strength and world leadership would probably cause greater suffering. As poorly as we model the global climate, even these physical results are more realistic than predictions of economic and social impacts which build upon the imperfect climate model output. In short, the impacts to human existence of a doubling or tripling of CO_2 are almost impossible to predict when one considers our present level of ignorance in these matters.

PREPARED STATEMENT OF RICHARD S. LINDZEN, ALFRED P. SLOAN PROFESSOR OF METEOROLOGY, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

I wish to thank Senators Chafee and Baucus, as well as the members of the Senate Committee on Environment and Public Works, for the opportunity to put forward my views on the issue of putative global warming.

INTRODUCTION

The issue of global warming is one of the more contentious issues in science today. Superficially, it is frequently portrayed as a 'simple' issue. Gases which absorb infrared radiation (known as greenhouse gases) inhibit radiative cooling of the earths

surface and hence increasing greenhouse gases must lead to warming. The issue is rendered more complex by the fact that the surface of the earth does not cool primarily by means of radiation, but rather cools by evaporation and convection. Moreover, the main greenhouse gas is water vapor which is both natural in origin and highly variable in its distribution. In the absence of good records of water vapor we aren't even in a position to say how much total greenhouse gases have increased. If this weren't bad enough, it isn't even the total amount of greenhouse gas which matters; for example, a molecule of water vapor at 12 km altitude is more effective than a thousand molecules near the surface. All of this might not be relevant if models were trustworthy, but satellite measurements of upper level water vapor show profound discrepancies in model results. Under the circumstances, it is surprising that there is any agreement among scientists, but, in fact, most scientists working on climate dynamics would agree that increasing levels of carbon dioxide should have some impact on climate. The real argument is over whether the impact will be significant. The word 'significant,' in this context, has a rather specific meaning. The climate is a naturally variable system. That is to say, it varies without any external forcing. Human society already has to deal with this degree of variability over which it has no control. For anthropogenic climate change to be 'significant,' it must be as large or larger than natural variability. For smaller changes, the historical record demonstrates our capacity to adapt. It is in this context that the statement frequently drawn from the 1995 IPCC (Intergovernmental Panel on Climate Change) report assumes some relevance. It is important, therefore, to know precisely what this statement does and doesn't say. Although it is likely that the statement is also incorrect, that turns out to be less important.

DISCERNABLE INFLUENCE

Let us begin by quoting this statement (which, in contrast to earlier IPCC reports, gives considerable more attention to important caveats):

> "Our ability to quantify the human influence on global climate is currently limited because the expected signal is still emerging from the noise of natural variability, and because there are uncertainties in key factors. These include the magnitude and patterns of long-term natural variability and the time-evolving pattern of forcing by, and response to, changes in concentrations of greenhouse and aerosols, and land-surface changes. Nevertheless, the balance of evidence suggests that there is a discernible human influence on global climate."

What it says is that the climate's behavior over the past century appears "unlikely to be due entirely to natural variability (IPCC 1995, p. 412)." As Chapter 8 of IPCC 95 points out, even this trivial assertion, which, as I have noted, seems totally compatible with our theoretical understanding and makes no claims concerning the magnitude of global warming, is dependent on the assumption that natural variability is replicated in models (IPCC 95 p. 430) an assumption which is clearly untrue since major observed components of natural variability like the quasi-biennial oscillation and El-Niño are either not replicated at all or replicated very poorly. Indeed the very structure of the circulation in models is different from what is observed in the data (Polyak and North, 1997). The specific feature which led Santer (the lead author of Chapter 8 of IPCC 95) to claim discovery of the discernible impact of anthropogenic forcing fails the most elementary test of statistical robustness: namely, it disappears when additional data is considered. Chapter 8 concludes that our ability to quantify the magnitude of global warming "is currently limited by uncertainties in key factors, including the magnitude and patterns of longer-term natural variability and the time-evolving patterns of forcing by (and response to) greenhouse gases and aerosols." In brief, a decade of focus on global warming and billions of dollars of research funds have still failed to establish that global warming is a significant problem. Normally, this would lead one to conclude that the problem is less serious than originally suggested. While the IPCC 1995 report does not go so far as to state this explicitly, it is certainly the most subdued and reserved of the numerous IPCC reports issued since 1990.

It has been a remarkable example of semantic distortion that this weak and unsupportable statement has encouraged environmental advocates to claim that this report endorses various catastrophic scenarios. An appeal issued a few days ago by one such organization, The Union of Concerned Scientists, illustrates the general procedure. The statement begins with a clear misrepresentation of the IPCC statement: "Predictions of global climatic change are becoming more confident. A broad consensus among the world's climatologists is that there is now 'a discernible human influence on global climate.'" The UCS immediately continues: "Climate change is projected to raise sea levels, threatening populations and ecosystems in

coastal regions. Warmer temperatures will lead to a more vigorous hydrological cycle, increasing the prospects for more intense rainfall, floods, and droughts in some regions. Human health may be damaged by greater exposure to heat waves and droughts, and by encroachment of tropical diseases to higher latitudes." The UCS proceeds to then associate climate change with forest depletion, water scarcity, food security, and species destruction. It concludes that scientists must endorse a strong climate treaty at Kyoto. The implication is that the so-called IPCC consensus extends to these claims as well. This is clearly a misrepresentation of the IPCC.. I use the phrase 'so-called' advisedly. The IPCC went to great lengths to include as many names as possible among its contributors. Against my expressed wishes, even my name was included. I can assure the committee that I (and the vast majority of contributors and reviewers) were never asked whether we even agreed with the small sections we commented on. Nevertheless, the usual comment is that 2,500 scientists all agree with whatever it is that the environmental advocates are claiming. To the credit of the IPCC, it extensively documented the shortcomings of various projections, and made few claims for any confidence. The document was deeply biased insofar as it took as its task the finding of global warming rather than the more objective approach of determining whether it is indeed a significant problem. Such an approach could be rationalized on the basis of sincere concern. However, even this document puts forward comments which are misleading. For example, on page 45 which deals with potential surprises, the possibility of an instability of the West Antarctic ice sheet is mentioned without any reference to the fact that such an unlikely instability is largely unrelated to climate (Bentley, 1997).

Genuinely Misleading Statement

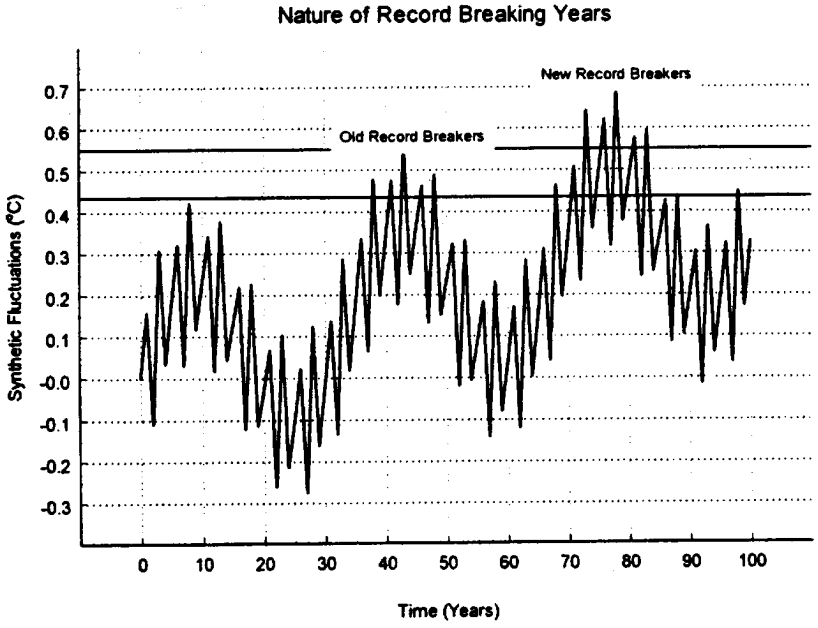


Figure 1

One of the common claims in support of the reality and seriousness of global warming is that we have had a large portion of record breaking warm years during the last decade or so. This is not a claim used by the IPCC, and its presence in any discussion is a rather clear piece of evidence of the intent to deceive (especially when the claim is made by a scientist). As noted by Solow and Broadus (1989) and Bassett (1992), this is an inevitable occurrence when one has a single record breaker in a time series characterized by interannual variability, interdecadal variability and an underlying trend or longer period variability. Solow and Broadus show the clustered nature of record breakers. For those who can follow some mathematics, the situation is easily synthesized as follows.

Let us represent the time series for temperature by the following expression:

$$f(t) = 0.2\sin(0.8\pi t) + 0.2\sin(\frac{2\pi t}{34}) + 0.4\frac{t}{100}$$

where the first term corresponds to interannual variability, the second term to interdecadal variability, and third to longer term trends or variability. This series is shown in Figure 1.

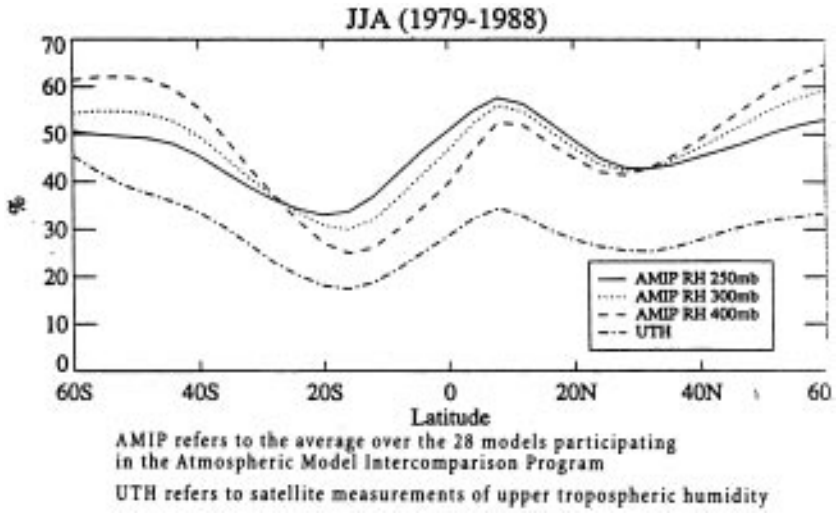
Not surprisingly, record breakers cluster in exactly the manner found by Solow and Broadus (1989) in the observed temperature record. The occurrence of such record breakers contributes no additional information. Our prime concern remains with the determination of trend and the identification of such trends with emissions of carbon dioxide, and this remains a difficult and contested issue as the IPCC freely acknowledges.

Scientific Waffling

S. Fred Singer has recently reported that the former head of the IPCC, Bert Bolin, has denied claims by Vice President Gore and environmental activists that "any floods, droughts, hurricanes, or other extreme weather patterns are the result of rising global temperatures." Bolin is quoted as saying "There has been no effect on countries from any current change," adding that efforts by activists to establish such a link "is why I do not trust the Greens." Although I was not present at the debate where Bolin is alleged to have made this remark, my personal experience suggests that it may be true. In 1993 at a mock trial of global warming held by the BBC in which both Bolin and I participated, Bolin made similar admissions. Nevertheless, in response to Singer's claims, Bolin has issued a formal denial. It may be of interest to look at this denial in some detail.

"Observations show that some extreme events are becoming more intense (heavy rainfall events in some regions), some are becoming less intense (cold spells), while others show no statistically significant changes (hurricanes). These changes are consistent with the kind of changes that would be associated with a warmer climate. While it cannot yet be concluded that these changes are caused by human-induced changes of climate, neither can this association be excluded. To state that these sorts of changes that 'are consistent' with the predicted effects of climate change, as Vice-President Gore is quoted to have stated, is a scientifically accurate statement and no cause for criticism."

In saying this, Bolin parts company with normative science which recognizes the virtual impossibility of disproving unverifiable assertions and sticks to statements that are capable of 'falsification.' 'Consistency,' in this context merely means that the situation is so unclear that virtually anything is will 'be consistent.' In the long run, the replacement of the precise and disciplined language of science by the misleading language of litigation and advocacy may be one of the more important sources of damage to society incurred in the current debate over global warming.



AMIP refers to the average over the 28 models participating in the Atmospheric Model Intercomparison Program

UTH refers to satellite measurements of upper tropospheric humidity

What can be said of the influence of increasing carbon dioxide?

Since the Charney Report of the NRC in 1979, the range of expected equilibrium global warming due to doubling carbon dioxide has been stated to be from about 1½C to 5½C. This is simply a statement of the range of results obtained by existing models, and assumes, somewhat illogically, that the correct answer must be in the output of at least one model. However, as frequently noted by the IPCC, the correct answer depends on correctly simulating feedbacks which, at present, are only poorly known and modeled. Despite this uncertainty,there are some aspects of the problem that are somewhat better known. In general, the response to doubled carbon dioxide (or equivalent carbon dioxide where the effect of other anthropogenic greenhouse gases is expressed in terms of 'equivalent' carbon dioxide) in the absence of feedbacks is taken to be the response when all other atmospheric parameters are held constant. The changes due to concomitant changes in other parameters are called feedbacks. There is some disagreement over whether one should consider the distribution of temperature change as a feedback. If one does, then the no-feedback equilibrium response to doubled carbon dioxide is about 0.3½C (Lindzen, 1995a); if one does not, then the no-feedback response is about 1.2½C. The latter is much larger than the former because it includes the warming effect at the surface of cooling in the stratosphere. If one takes the latter approach, then the most important feedback is due to upper level (above about 2 km) water vapor. In all existing models (in the original models by explicit assumption), water vapor, the most important greenhouse gas, increases at all levels as surface temperature increases, doubling the no-feedback response to doubled carbon dioxide. The presence of the positive water vapor feedback in current models also increases the sensitivity of these models to other smaller feedbacks such as those due to clouds and snow reflectivity. The trouble with current models is that they generally lack the physics to deal with the upper level water vapor budget, and they are generally unable, for computational reasons, to properly calculate a quantity like water vapor which varies sharply both vertically and horizontally (Sun and Lindzen, 1993, Lindzen, 1995). Indicative of these problems is the recent work of J.J. Bates and D.L. Jackson at NOAA who found, using satellite data from infrared sounders, that, on the average, current models underestimate zonally averaged (averaged around a latitude circle) water vapor by about 20 percent. This is illustrated in Figure 2. It should be noted that this represents an error in radiative forcing of about 20 Watts per square meter, as compared with the forcing of 4 Watts per square meter due to a doubling of carbon dioxide (Thompson and Warren, 1982, Lindzen, 1995). More recent observational analyses by Spencer and Braswell (1997), using satellite microwave data, suggest that even Bates and Jackson have overestimated water vapor, and that the discrepancy with models is still greater. Under the circumstances, there seems to be little actual basis for the most important positive feedback in models. Given our in-

ability to detect expected warming in the temperature data, one might reasonably conclude that models have overestimated the problem.

In some ways, we are driven to a philosophical consideration: namely, do we think that a long-lived natural system, like the earth, acts to amplify any perturbations, or is it more likely that it will act to counteract such perturbations? It appears that we are currently committed to the former rather vindictive view of nature.

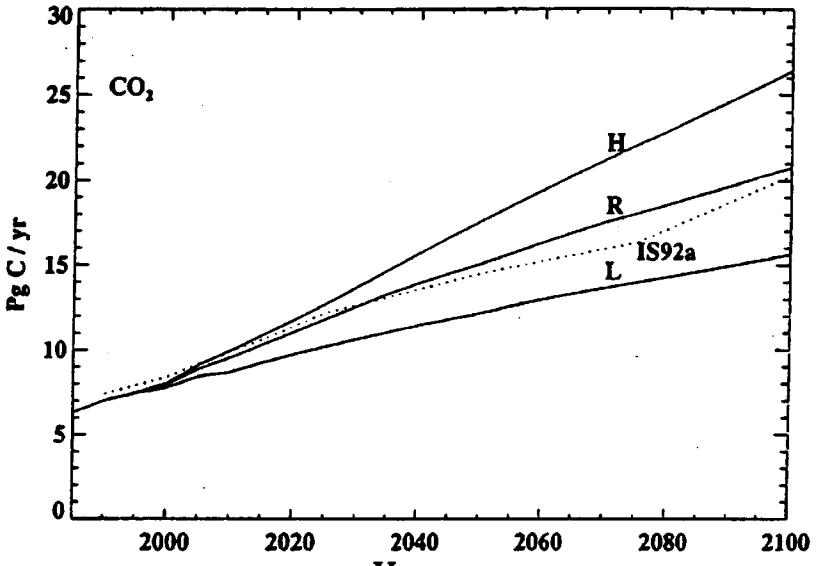


Figure 3

What can be said of the implications of proposed policies for climate?

The above remarks dealt with the issue of global warming as a phenomenon. However, the current political concern deals with the proposed setting of firm emission limitations at the forthcoming Kyoto meeting in December. The underlying assumption is that stabilization of emissions at 1990 levels (or modest reductions of these levels) would spare the world from global warming, should the more extreme model forecasts prove correct (despite the patent shortcomings of these models, and the absence of convincing confirmation in existing data). It is important, therefore, to note that such emissions reductions would have no such effect regardless of what one believes about global warming. The effects of either lesser reductions or of restricting emission reductions to the developed world would be even more negligible in terms of climate impact. This is illustrated in Figures 3 and 4 taken from a recent report of Prinn et al (1997) based on the model developed for MIT's Program on the Science and Policy of Global Change. Figure 3 shows carbon dioxide levels for a variety of scenarios. The levels by 2100 vary from about 590 ppmv to 950 ppmv. Figure 4 shows global mean temperature change for various conditions indicated by three letters. The first letter refers to emissions, with H associated with the high values in Figure 3 and L with the low values; R refers to a reference case. The second letter refers to the ocean delay with H referring to short delay and L referring to long delay. The third letter refers to climate sensitivity with H referring to an equilibrium sensitivity to doubled carbon dioxide of about 4.5°C, and L to a sensitivity of about 1.5°C. We see that for high climate sensitivity we will get pronounced warming regardless of emission scenario, while for low sensitivity, emission scenarios will not matter. It is important to note that emission caps proposed for Kyoto, as difficult and expensive as they may prove, will not prevent global warming if the climate should prove sensitive. The impact of any proposed policy, currently reckoned as even marginally feasible, will likely be impossible to ascertain regardless of what the climate sensitivity is. However, what Figure 4 does tell us is that should there be little warming over the next 50 years, it won't be because of any policy we implement at Kyoto.

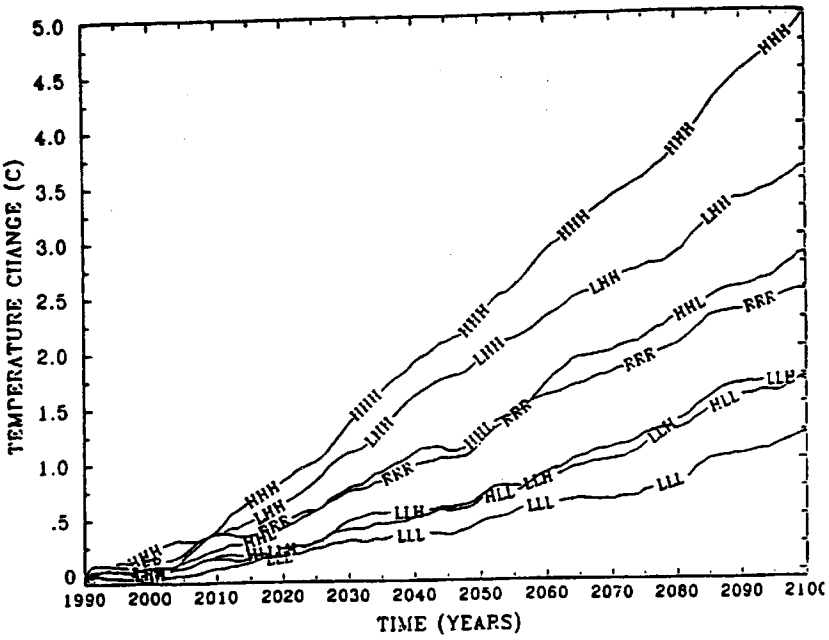


Figure 4

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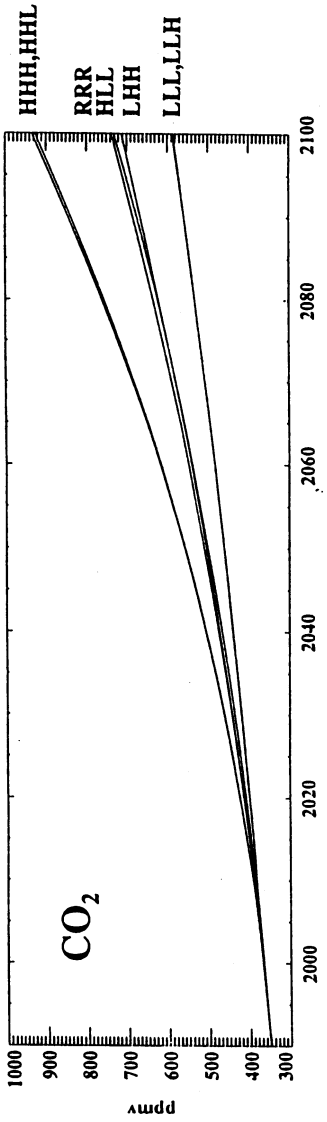
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RESPONSES BY RICHARD LINDZEN TO ADDITIONAL QUESTIONS FROM SENATOR BAUCUS

Response 1. Dr. Barron's suggestion was intentionally generic rather than specific. Moreover, adaptive policies require something to adapt to, and in the words of Bert Bolin, the former head of the IPCC, "There has been no effect on countries from any current change. The increases in temperature have been so small as to be barely detectible." Thus, at the moment, there is nothing special to adapt to. In the longer term, we can plausibly expect many things to change over the next century including the climate (even without any influence from man) in almost totally unanticipated ways. It thus behooves us to continue to develop a society that can successfully deal with and exploit change. The obvious tools for this are wealth and capital, information and education, as well as flexibility, freedom and intelligence.

Response 2. Frankly, I do not know the basis for Dr. Schneider's remark. However, it is obvious that species respond to local rather than global conditions, and locally, changes on the order of 1.5°C and more have occurred over the past century or even less. This has led to some modest species migration and changes in agriculture, but not, to the best of my knowledge, to extinctions. What I suspect Dr. Schneider may be referring to is the fact that climate change in the past, forced by changing patterns of heating, among other things, rather than gross global heating, has been characterized by large changes in the temperature difference between the tropics and the poles rather than changes in global mean temperature. Thus, by some reckonings during the last major glaciation global mean temperature may only have been about 8°C colder than at present. Indeed, both glaciation and deglaciation led to species extinctions for creatures that had specifically adapted to the earlier climate and terrain. Even so, these were not among the major periods of species loss.

Response 3. First, let me state that predictions of large climate change already require that these mechanisms act to amplify the changes due to increasing anthropogenic greenhouse gases. There is no credible evidence for this. The warming expected from a doubling of CO_2 even in the absence of any natural thermostatic control would only be about 1°C (and about 1.5°C for a tripling; the effect is not linear). This low level of warming calls for no mechanism whatever to counteract the effect of increased anthropogenic greenhouse gases. Predictions of greater warming actually require that water vapor act in such a way as to increase the warming by a factor of two and more. I intentionally refer to the action of water vapor rather than to the amount of water vapor. Water vapor in the atmosphere is extremely heterogeneous. There are regions that are very dry and regions that are very moist. Most water vapor resides in the lowest 2–3 km of the atmosphere, but it is water vapor above this level that is most important to the greenhouse effect (E. Schneider et al, 1997, Shine and Sinha, 1991). Moreover, most radiative cooling occurs in dry regions, and cooling would increase if the dry regions increased in area even if the net water vapor increased. Understanding the water vapor feedback in dry regions is central to determining the feedback. Here, the budget of water vapor consists in drying due to subsiding air and moisturizing from the evaporation of ice thrown off by clouds rather than directly falling as rain (Sun and Lindzen, 1993, describe the water vapor budget in detail). If claims of an intensified hydrological cycle in a warmer climate prove correct, then the drying term will increase. Moreover, the amount of ice thrown off depends on the precipitation efficiency of clouds. The more efficient the clouds, the less ice there is to throw off According to every text on cloud physics written over the past half century, precipitation efficiency increases with increasing temperature (Fletcher, 1962, Mason, 1971, Rogers and Yau, 1989 for example). Thus we expect the moisturizing to decrease. Both effects should lead to an expansion of the dry regions which would counteract the effect of increasing CO_2. This is the opposite of what current models display, which is not surprising since current models completely fail to produce dry regions of the sort observed in satellite data (Spencer and Braswell, 1997).

Response 4. The IPCC conclusion was based on the then unpublished work of Santer et al (1996). This work used radiosonde (balloon) data from sometime in the 70's until 1987. As shown by Michaels and Knappenberger (1996) when the available radiosonde data until 1995 was used, the effect that Santer et al claimed to have found (a correlation between observations and model predictions) disappeared. Another study by some of the same authors who participated in Santer et al also reached the conclusion that the earlier study was not statistically robust (Tett et al, 1996). In fact, studies examining the results in Santer et al were not possible until after the publication of IPCC 95, since the Santer et al paper had not yet appeared when IPCC 95 was published. This, of course, is counter to the claimed policy of the IPCC. That said, the Santer et al paper never claimed to quantify the

impact of human activities. The paper, moreover, acknowledged that even the meager result claimed was absolutely dependent on the assumption that natural variability was well replicated by model variability—a dubious assumption at best. Finally, the paper failed to consider whether the observed behavior could be due to other factors. The Santer et al paper and IPCC use of it are excellent examples of how virtually meaningless statements by scientists can be found by non-scientists to have dire import. In many cases, the scientists are by no means innocent of exploiting this difference in perception.

Response 5. No, I do not believe there is sufficient evidence to continue pursuing "some kind of policy to limit CO_2 emissions". If the only reason you can imagine for supporting climate research is the likelihood of catastrophe, then by all means stop funding research. However, in the light of my answer to your first question, this would seem short sighted indeed. Regardless of the current evidence or lack thereof, it seems to me that it would be unwise to make support of any science contingent on the projection of catastrophe.

Response 6. Predicting industrial trajectories is as difficult as any other kind of long term prediction. However, I personally think that it is entirely possible, in the light of our present imperfect knowledge, that atmospheric CO_2 levels in 2100 will be double present values. About the only effect of this that we are presently reasonably sure of is that plant growth will increase, and plant susceptibility to water stress will decrease. As concerns climate, we have already had a 50 percent increase in 'effective' CO_2 since the last century, and hardly anyone has noticed. There is no compelling evidence that matters will change dramatically with further increases.

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RESPONSE BY RICHARD LINDZEN TO AN ADDITIONAL QUESTION FROM SENATOR BOXER

Response. The most famous cycle of climate change we know of is the 100,000 year cycle of glaciation usually identified with orbital variations. Numerous climate changes on shorter time scales have been observed, though it is hardly clear that these are cyclic. Among the more famous climate events of the holocene (the period since the last ice age) are the mid-holocene optimum, the medieval optimum and the little ice age. Traditionally, warm periods were referred to as optima. Regionally, many regions have undergone climate change that may be peculiar to those regions. In fact, regional variability is generally much larger than global variability. Even within this century, there appears, for example, to have been a significant winter cooling trend in north Florida. On relatively short time scales, climatic variations associated with El Niños are beginning to be understood. However, although strong interdecadal variability is evident in the data, its cause is not understood. What is increasingly clear is that the atmospheric system is capable of variability without external forcing, and that variability is the norm rather than the exception. The detection of change due to human activity amidst all this natural variability is, indeed, a difficult task. However, it would not be difficult if warming were to be progressing at the rate suggested in the 1990 IPCC report (0.3°C per decade).

Your last question clearly transcends science. I would normally be sympathetic to your suggestion if it were cost-free. However, as I noted in my testimony, presently suggested policies like limiting emissions to 1990 levels would have little impact on either CO_2 buildup or projected warming (regardless of model or belief). Moreover, without the participation of all nations, the impact would be essentially nil. Thus, we are suggesting potentially large costs (both in terms of money and regulatory burden) for certifiably small benefits. This really does not seem to make much sense on the face of it.

PREPARED STATEMENT OF STEPHEN H. SCHNEIDER, PROFESSOR, DEPARTMENT OF BIOLOGICAL SCIENCES, STANFORD UNIVERSITY

CLIMATE CHANGE: CAUSES, IMPACTS AND UNCERTAINTIES

I. Does Natural Variability Explain All Climate Change?

Twenty thousand years ago, a mere blink in geologic time, a visitor to the now-productive Corn Belt of Illinois would not be sitting in the heart of the world's foremost granary, but rather open spruce parkland forest, where many of the tree species seen are the same kinds that are found today 500 to 1,000 miles north in the Boreal Forests of Canada. Similarly, if we could somehow have been flying over the Great Basin we would have seen the massive fossil lakes, some stretching hundreds of miles like former Lake Bonneville in Utah, and the now-fossil beaches (currently visible flying into Salt Lake City Airport or over Mono Lake) from those high water stands that date back 10 to 15 thousand years ago. The Ice Age, which at its maximum some 20,000 years ago was about 5° to 7°C (around 100°F) colder than our current global climate, disappeared in, what is to nature, a relatively rapid period of about 5,000 to 10,000 years. The average rate of temperature change from the Ice Age to the current 10,000 year period of relative climate stability, our so-called Holocene Interglacial, is about 1°C change for every thousand years. Of course there were more rapid periods embedded within this timeframe, but I'm only giving the sustained average rates.

Not only did such change correspond with radical alterations to the ecosystems of the earth, but have been implicated in the extinction of what is known as the charismatic megafauna (woolly mammoth, saber tooth tigers, etc.). Fossil pollen evidence tells us that the vegetation habitats during the more "rapid" parts of the transition from ice age to interglacial around 10 to 12 thousand years ago saw what paleoclimatologists call "no analog habitats," that is, combinations of pollen abundances which do not exist on earth today. All of this change was natural, of course, and there are two reasons for mentioning it in our context. First, to remind us that the climate and ecosystems change by themselves, without need of humans (the latter is what we call anthropogenic causation), and second, that climate change of about several degrees on a global average basis is a very significant change from the point of view of natural systems.

Explanations of the Ice Age vary, the most popular one being a change in the amount of sunlight coming in between (a) winter and summer and (b) the poles and the equator. These changes in the distribution of seasonal or latitudinal sunshine are due to slow variations in the tilt of the earth's axis and other orbital elements, but these astronomical variations alone cannot totally explain the climatic cycles. If these orbital variations and other factors (such as the increased reflectivity of the earth associated with more ice) are combined, our best climate theories (embodied through mathematical models that are comprised of the physical laws of conservation of mass, energy and momentum) suggest that the Ice Age should have been several degrees warmer than it actually was—especially in the Southern hemisphere. What could account for this extra cold? Perhaps the models are not sensitive enough, that is they do not respond sufficiently to a change in so called "radiative climate forcing," that is the change in the amount of radiant energy coming to the earth from external factors like orbital variations or extra ice. Another (more likely, I think) possibility is that something else also changed at the same time.

These theories can be better reconciled with what happened between ice ages and interglacials if one assumes that several watts of energy over every square meter of the earth were taken away in the ice age by some other mechanism at a global scale. But what could be such a mechanism? The obvious candidate would be a change in the composition of the earth's atmosphere which affects both its reflectivity and its heat trapping capacity (e.g., decreases in the well-known greenhouse effect or increases in atmospheric dust). But what evidence is there that greenhouse gases, for example carbon dioxide, methane, nitrous oxide, or water vapor, had lower concentrations 20,000 years ago than in the interglacial? About 15 years ago that

evidence came through loud and clear from the ice caps of the world. Air trapped in these glaciers provides a library of the history of the earth's atmosphere back some 200,000 years. It shows that during the past two ice ages carbon dioxide concentration was about 40 percent less and methane half of the average value during the current and penultimate interglacials. It also shows that since the Industrial Revolution carbon dioxide has increased beyond any levels experienced in the past 150,000 years (at least) by nearly 30 percent and methane by 150 percent—two figures that virtually no knowledgeable scientist disputes are a result of so-called anthropogenic emissions which are driven by increasing numbers of people pursuing higher standards of living and using technology to achieve those growth-oriented goals.

If the carbon dioxide and methane decreases in the last ice age helped to explain the ice age coldness, can they tell us something about how the anthropogenic increase of these gases due to human activities might cause climate change in the future? The answer is "not directly," for it is possible that there are other factors we have not accounted for in the ice age story that could well have been involved, and there are still many unanswered questions associated with the Ice Age cycles. It is simply a circumstantial bit of evidence which suggests that it is more consistent to explain the ice ages with the heat trapping power of the greenhouse effect existing at the magnitudes currently envisioned by most scientists—i.e. a doubling of CO_2 would raise surface temperatures by about 3°C plus or minus 1.5°C. This is known as the "climate sensitivity range." The magnitude of climate sensitivity that helps to explain the ice age coldness best is 2–3°C. If the best estimate were ten degrees warming, which is twice the value at the high end of the climate sensitivity range thought by the mainstream of scientist today (e.g., IPCC 1996a), then the ice ages should have been even colder than they were. On the other hand, if the earth would only warm up by half a degree or less if CO_2 doubled, then it would be tougher to explain the magnitude of the ice ages without finding some other mechanism not yet understood. Of course, the latter is possible, but what other lines of circumstantial evidence or direct evidence do we have for estimating climate sensitivity?

We know from quite literally thousands of laboratory experiments and direct measurements, millions of balloon observations and trillions of satellites data bits, that the basic structure of the energy flows in and out of the earth's atmosphere are relatively well understood. We know that water vapor, carbon dioxide, or methane trap enough energy on the earth to warm the surface up about 33°C (60°F) relative to that which would occur in their absence.

This well known natural greenhouse effect is not under dispute, and has been known for a century and a half. Nor is the 0.5°C (plus or minus 0.2°C) globally averaged warming trend at the earth's surface over the past century in dispute. In dispute is whether a small increment since the Industrial Revolution in this envelope of greenhouse gases, which our calculations tell us should have trapped about two extra watts of energy over every square meter of Earth, would produce a noticeable response (i.e. a "climate signal"). The debate over whether that signal has been detected has been intense lately and this intensity has been based upon significant new pieces of evidence—albeit each piece is circumstantial—and a few loud, well-publicized denials that the totality of evidence has any meaning. In the absence of clear, direct empirical evidence, one often has to use either circumstantial evidence, or incomplete bits of direct evidence with uncertainties attached. When the preponderance of such evidence gets strong enough, then most scientists begin to accept, tentatively of course, the likelihood of causal connections. Some people shed their skepticism at different levels than others, so naturally there will be a cacophonous debate over whether a climate signal has been detected, let alone whether it could be attributed to human activities. One can always find some scientist who will want 999 out of a 1,000 probability of certainty, and others who will accept the proposition at eight or nine chances out of ten. This is not science, but a value judgment about the acceptability of a significant, but not conclusive, body of evidence. The scientific job is to assess (A) what can happen, and (B) what the odds are of it happening (see, for example, this discussion in Chapter 6 of Schneider 1997a). Let me discuss this process further.

I have mentioned the ice ages since this is a "natural experiment" that we use, not to forecast the future, but to build understanding of climate processes and to validate the tools that we do use to forecast the future—that is, our climate theories embodied in mathematical models. Are there any other such natural experiments? The answer is "yes there are many," the two most prominent being (1) episodic volcanic eruptions which throw dust in the stratosphere that reflects for a few years a few watts per square meter of solar energy that otherwise would have reached the lower atmosphere and (2) the seasonal cycle. Let's consider volcanic eruptions first. Volcanic dust veils should cool the planet. In fact, the last major eruption, Mt.

Pinatubo in 1991, was forecast to cool the earth's lower atmosphere on the order of several tenths of a degree by a number of climate modeling groups—in advance of the actual data to confirm—and indeed, that is roughly what happened. However, it could be argued that a few tenths of a degree cooling, or warming for that matter, might be a natural fluctuation in the earth's climate system, and indeed, fluctuations of that magnitude are a part of the natural background "climatic noise." How then could we distinguish the climatic signal of the volcanic eruption from the noise of the natural variability? In any one eruption it is difficult to do so since the signal to noise ratio is about one, i.e. the magnitude of the cooling expected is about equal to the magnitude of the natural fluctuations in non-volcanic years, and therefore for any one event we cannot have very much confidence that a signal has been observed. So the fact that the Pinatubo results showed up about as predicted doesn't, by itself, give a lot of confidence, although as a circumstantial bit of evidence is quite useful. However, another volcanic eruption in 1983, El Chichón, was also followed by several tenths of a degree cooling, as was the effect after Mt. Agung in 1963 or Mt. Krakatoa in the Victorian period.

In other words, by looking at the results of several volcanic eruptions and compositing, a number of scientists (including Mass and Schneider, 1977) used this technique and discovered that indeed there was a clear and obvious correlation which suggests that when a few watts of energy over every square meter of the earth is removed by volcanic dust veils in the stratosphere, the lower atmosphere will indeed cool by a few tenths of degrees—the very magnitude predicted by the same computer models that we use to forecast the effects of a few watts per square meter of sustained heating from global warming.

What other natural experiments might we have to test climate sensitivity? My favorite is one that happens every year—the seasons. Winter predictably follows summer, being some 15 degrees colder in the Northern Hemisphere and five degrees colder than summer in the Southern Hemisphere. The reason the Southern Hemisphere has a smaller seasonal cycle is because it has much more ocean than land, and water has a higher heat retaining capacity than land or air. Since a season is not long enough for the planet to reach an equilibrium temperature change, therefore, the more land dominated Northern Hemisphere has lower heat capacity and thus a larger seasonal cycle of surface temperature. How well do the climate models do in reproducing this change? The answer is "extraordinarily well." Although what the absolute temperatures models may simulate can be off by as much as five or six degrees in some regions of the world for some seasons, the models' capacity to reproduce the amplitude of the seasonal cycle of surface air temperatures, by and large, is quite good. (It is less good for other variables, however, particularly hydrological systems.) Now, if we were making a factor of ten error by either overestimating or underestimating the sensitivity of the climate to radiative forcing, it would be difficult for the models to reproduce the different seasonal cycle surface temperature amplitudes over land and oceans as well as they do. This is another piece of circumstantial evidence suggesting that current estimate of climate sensitivity is not off by a factor of ten, as some "contrarians" assert. Indeed, indirect evidence like ice ages, volcanic eruptions and the seasonal cycle simulation skills of models are prime reasons why many of us in the scientific community have for the past 20 years expected that "demonstrable" (e.g., see p.11 of Schneider and Mesirow, 1976—in which I projected just such a change) anthropogenic climate change was not unlikely by the 21st century.

In summary, then, in my opinion it is unlikely that natural variability is the explanation of all climate change, especially that which has been documented in the 20th century. However, since much of the debate over detection and attribution of human-caused climate change hinges on the projections of climatic models, it is necessary to have at least a cursory understanding of how they work. Although it is impossible to treat more than the highlights of the nature and use of climatic models in a dozen pages, I nonetheless offer the following section in the hopes of reducing somewhat the confusion that may exist in many peoples' minds after listening to the often acrimonious and technically complex debate over climatic models and their credibility.

II. Overview Of Climate Modeling Fundamentals

Engineers and scientists build models—either mathematical or physical ones—primarily to perform tests that are either too dangerous, too expensive, or perhaps impossible to perform with the real thing. To simulate the climate, a modeler needs to decide which components of the climatic system to include and which variables to involve. For example, if we choose to simulate the long-term sequence of glacials and interglacials (the period between successive ice ages), our model needs to include explicitly the effects of all the important interacting components of the climate

system operating over the past million years or so. These include the atmosphere, oceans, sea ice/glaciers (cryosphere), land surface (including biota), land sub-surface and chemical processes (including terrestrial and marine biogeochemical cycles), as well as the external or "boundary forcing" conditions such as input of solar radiant energy (e.g., see IPCC, 1996a).

The problem for earth systems scientists is separating out quantitatively cause and effect linkages from among the many factors that interact within the earth system. It is a controversial effort because there are so many sub-systems, so many forcings and so many interacting complex sets of processes operating at the same time that debates about the adequacy of models often erupt.

Modeling the Climate System. So how are climate models constructed? First, scientists look at observations of changes in temperatures, ozone levels and so forth. This allows us to identify correlations among variables. Correlation is not necessarily cause and effect—just because one event tracks another doesn't mean it was caused by it. One has to actually prove the relationship is causal and explain how it happened. Especially for cases where unprecedented events are being considered, a first principles, rather than a purely empirical-statistical approach is desirable. However, observations can lead to a hypothesis of cause and effect—"laws"—that can be tested (for example, see Root and Schneider, 1995). The testing is often based on simulations with mathematical models run on a computer. The models, in turn, need to be tested against a variety of observations—present and paleoclimatic. That is how the scientific method is typically applied. When a model, or set of linked models, appear plausible, they can be fed "unprecedented" changes such as projected human global change forcings—changes that have not happened before—and then be asked to make projections of future climate, ozone levels, forests, species extinction rates, etc.

The most comprehensive weather simulation models produce three dimensional details of temperature, winds, humidity, and rainfall all over the globe. A weather map generated by such a computer model—known as a general circulation model or GCM—often looks quite realistic, but it is never faithful in every detail. To make a weather map generated by computer we need to solve six partial differential equations that describe the fluid motions in the atmosphere. It sounds in principle like there's no problem: we know that those equations work in the laboratory, we know that they describe fluid motions and energy and mass relationships. So why then aren't the models perfect simulations of the atmospheric behavior?

One answer is that the evolution of weather from some starting weather map (known as the initial condition) is not deterministic beyond about 10 days—even in principle. A weather event on 1 day cannot be said to determine an event 20 days in the future, all those commercial "long-range" weather forecasts notwithstanding. But the inherent unpredictability of weather details much beyond 10 days (owing to the chaotic internal dynamics of the atmosphere) doesn't preclude accurate forecasts of long-term averages (climate rather than weather). The seasonal cycle is absolute proof of such deterministic predictability, as winter reliably follows summer and the cause and effect is known with certainty.

Grids and Parameterization. The other answer to the imperfection of general circulation model simulations, even for long-term averages, is that nobody knows how to solve those six complex mathematical equations exactly. It's not like an algebraic equation where one can get the exact solution by a series of simple operations. There isn't any known mathematical technique to solve such coupled, nonlinear partial differential equations exactly. We approximate the solutions by taking the equations, which are continuous, and breaking them down into discrete chunks which we call grid boxes. A typical GCM grid size for a "low resolution" model is about the size of Colorado horizontally and that of a "high resolution" GCM is about the size of Connecticut. In the vertical dimension there are two (low resolution) up to about 20 (high resolution) vertical layers that are typically spanning the lowest 10 to 40 kilometers of the atmosphere.

Now, we've already noted that clouds are very important to the energy balance of the earth-atmosphere system since they reflect sunlight away and trap infrared heat. But because none of us have ever seen a single cloud the size of Connecticut, let alone Colorado, we have a problem of scale—how can we treat processes that occur in nature at a smaller scale than we can resolve by our approximation technique of using large grid boxes. For example, we cannot calculate clouds explicitly because individual clouds are typically the size of a dot in this grid box. But we can put forward a few reasonable propositions on cloud physics: if it's a humid day, for example, it's more likely to be cloudy. If the air is rising, it's also more likely to be cloudy.

These climate models can predict the average humidity in the gridbox, and whether the air is rising or sinking on average. So then we can write what we call a para-

metric representation or "parameterization" to connect large scale variables that are resolved by the grid box (such as humidity) to unresolved small scale processes (individual clouds). Then we get a prediction of grid box-averaged cloudiness through this parameterization. So-called "cumulus parameterization" is one of the important—and controversial—elements of GCMs that occupy a great deal of effort in the climate modeling community. Therefore, the models are not ignoring cloudiness, but neither are they explicitly resolving individual clouds. Instead, modelers try to get the average effect of processes that can't be resolved explicitly at smaller scales than the smallest resolved scale (the grid box) in the GCM. Developing, testing and validating many such parameterizations is the most important task of the modelers since these parameterizations determine critically important issues like "climate sensitivity." The climate sensitivity is the degree of response of the climate system to a unit change in some forcing factor: typically, in our context, the change in globally averaged surface air temperature to a fixed doubling of the concentration of atmospheric carbon dioxide above pre-industrial levels. This brings us to one of the most profound controversies in earth systems science, and one of the best examples of the usefulness, and fragility, of computer modeling.

The Greenhouse Effect. If the earth only absorbed radiation from the sun without giving an equal amount of heat back to space by some means, the planet would continue to warm up until the oceans boiled. We know the oceans are not boiling, and surface thermometers plus satellites have shown that the earth's temperature remains roughly constant from year to year (the interannual globally averaged variability of about 0.2°C or the 0.5°C warming trend in the 20th century, notwithstanding). This near constancy requires that about as much radiant energy leaves the planet each year in some form as is coming in. In other words, a near-equilibrium or energy balance has been established. The components of this energy balance are crucial to the climate.

All bodies with temperature give off radiant energy. The earth gives off a total amount of radiant energy equivalent to that of a black body—a fictional structure that represents an ideal radiator—with a temperature of roughly—18°C (255°K). The mean global surface air temperature is about 14°C (287°K), some 32°C warmer than the earth's black body temperature. The difference is due to the well-established greenhouse effect.

The term greenhouse effect arises from the classic analogy to a greenhouse, in which the glass allows the solar radiation in and traps much of the heat inside. However, the mechanisms are different, for in a greenhouse the glass primarily prevents convection currents of air from taking heat away from the interior. Greenhouse glass is not primarily keeping the enclosure warm by its blocking or re-radiating infrared radiation; rather, it is constraining the physical transport of heat by air motion.

Although most of the earth's surface and thick clouds are reasonably close approximations to a black body, the atmospheric gases are not. When the nearly black body radiation emitted by the earth's surface travels upward into the atmosphere, it encounters air molecules and aerosol particles. Water vapor, carbon dioxide, methane, nitrous oxide, ozone, and many other trace gases in the earth's gaseous envelope tend to be highly selective—but often highly effective—absorbers of terrestrial infrared radiation. Furthermore, clouds (except for thin cirrus) absorb nearly all the infrared radiation that hits them, and then they reradiate energy almost like a black body at the temperature of the cloud surface—colder than the earth's surface most of the time.

The atmosphere is more opaque to terrestrial infrared radiation than it is to incoming solar radiation, simply because the physical properties of atmospheric molecules, cloud and dust particles tend on average to be more transparent to solar radiation wavelengths than to terrestrial radiation. These properties create the large surface heating that characterizes the greenhouse effect, by means of which the atmosphere allows a considerable fraction of solar radiation to penetrate to the earth's surface and then traps (more precisely, intercepts and re-radiates) much of the upward terrestrial infrared radiation from the surface and lower atmosphere. The downward re-radiation further enhances surface warming and is the prime process causing the greenhouse effect.

This is not a speculative theory, but a well understood and validated phenomenon of nature. The most important greenhouse gas is water vapor, since it absorbs terrestrial radiation over most of the infrared spectrum. Even though humans are not altering the average amount of water vapor in the atmosphere very much by direct injections of this gas, increases in other greenhouse gases which warm the surface cause an increase in evaporation which increases atmospheric water vapor concentrations, leading to an amplifying or "positive" feedback process known as the "water vapor-surface temperature-greenhouse feedback." The latter is believed re-

sponsible for the bulk of the climate sensitivity (IPCC, 1996a). Carbon dioxide is another major greenhouse gas. Although it absorbs and re-emits considerably less infrared radiation than water vapor, CO_2 is of intense interest because its concentration is increasing due to human activities. Ozone, nitrogen oxides, some hydrocarbons, and even some artificial compounds like chlorofluorocarbons are also greenhouse gases. The extent to which they are important to climate depends upon their atmospheric concentrations, the rates of change of those concentrations and their effects on depletion of stratospheric ozone—which in turn, can indirectly modify the radiative forcing of the lower atmosphere thus changing climate—currently offsetting a considerable fraction of the otherwise expected greenhouse warming signal.

The earth's temperature, then, is primarily determined by the planetary radiation balance, through which the absorbed portion of the incoming solar radiation is nearly exactly balanced over a year's time by the outgoing terrestrial infrared radiation emitted by the climatic system to earth. As both of these quantities are determined by the properties of the atmosphere and the earth's surface, major climate theories that address changes in those properties have been constructed. Many of these remain plausible hypotheses of climatic change. Certainly the natural greenhouse effect is established beyond a reasonable scientific doubt, accounting for natural warming that has allowed the coevolution of climate and life to proceed to this point (e.g., see Schneider and Londer, 1984). The extent to which human augmentation of the natural greenhouse effect (i.e., global warming) will prove serious is, of course, the current debate.

Model Validation. There are many types of parameterizations of processes that occur at a smaller scale than our models can resolve, and scientists debate which type is best. In effect, are they an accurate representation of the large-scale consequences of processes that occur on smaller scales than we can explicitly treat? These include cloudiness, radiative energy transport, turbulent convection, evapotranspiration, oceanic mixing processes, chemical processes, ecosystem processes, sea ice dynamics, precipitation, mountain effects and surface winds.

In forecasting climatic change, then, validation of the model becomes important. In fact, we cannot easily know in principle whether these parameterizations are "good enough." We have to test them in a laboratory. That's where the study of paleoclimates has proved so valuable (e.g., Hoffert and Covey, 1992). We also can test parameterizations by undertaking detailed small-scale field or modeling studies aimed at understanding the high resolution details of some parameterized process the large-scale model has told us is important. The Second Assessment Report of IPCC (IPCC, 1996a) Working Group I devoted more than one chapter to the issue of validation of climatic models, concluding that "the most powerful tools available with which to assess future climate are coupled climate models, which include three-dimensional representations of the atmosphere, ocean, cryosphere and land surface. Coupled climate modeling has developed rapidly since 1990, and current models are now able to simulate many aspects of the observed climate with a useful level of skill. [For example, as noted earlier, good skill is found in simulating the very large annual cycle of surface temperatures in Northern and Southern Hemispheres or the cooling of the lower atmosphere following the injection of massive amounts of dust into the stratosphere after explosive volcanic eruptions such as Mt. Pinatubo in the Philippines in 1991.] Coupled model simulations are most accurate at large spatial scales (e.g., hemispheric or continental); at regional scales skill is lower". [sentence in square brackets added]

One difficulty with coupled models is known as "flux adjustment"—a technique for accounting for local oceanic heat transport processes that are not well simulated in some models. Adding this element of empirical-statistical "tuning" to models that strive to be based as much as possible on first principles has been controversial. However, not all models use flux adjustments, yet nearly all models, with or with out this technique, produce climate sensitivities within or near to the standard IPCC range of 1.5 to 4.5°C. Flux adjustments do, however, have a large influence on regional climatic projections, even if they prove not to be a major impact on globally averaged climate sensitivity. Improving coupled models is thus a high priority for climate researchers since it is precisely such regional projections that are so critical to the assessment of climatic impacts on environment and society (e.g., IPCC, 1996b; IPCC, 1997).

Transient versus Equilibrium Simulations. One final issue needs to be addressed in the context of coupled climate simulations. Until recently, climate modeling groups did not have access to sufficient computing power to routinely calculate time evolving runs of climatic change given several alternative future histories of greenhouse gases and aerosol concentrations. That is, they did not perform so-called transient climate change scenarios. (Of course, the real Earth is undergoing a transient experiment.) Rather, the models typically were asked to estimate how the Earth's

climate would eventually be altered (i.e., in equilibrium) after CO_2 was artificially doubled and held fixed indefinitely rather than increased incrementally over time as it has in reality or in more realistic transient model scenarios. The equilibrium climate sensitivity has remained fairly constant for over 20 years of assessments by various national and international groups, with the assessment teams repeatedly suggesting that, were CO_2 to double, climate would eventually warm at the surface somewhere between 1.5 and 4.5° C. (Later on we will address the issue of the probability that warming above or below this range might occur, and how probabilities can even be assigned to this sensitivity.)

Transient model simulations exhibit less immediate warming than equilibrium simulations because of the high heat holding capacity of the thermally massive oceans. However, that unrealized warming eventually expresses itself decades to centuries later. This thermal delay, which can lull us into underestimating the long-term amount of climate change, is now being accounted for by coupling models of the atmosphere to models of the oceans, ice, soils, and biosphere (so-called earth system models—ESMs). Early generations of such transient calculations with ESMs give much better agreement with observed climate changes on Earth than previous calculations in which equilibrium responses to CO_2 doubling were the prime simulations available. When the transient models at the Hadley Center in the United Kingdom and the Max Planck Institute in Hamburg, Germany were also driven by both greenhouse gases (which heat) and sulfate aerosols (which cool), these time evolving simulations yielded much more realistic "fingerprints" of human effects on climate(e.g., Chapter 8 of IPCC, 1996a). More such computer simulations are needed to provide high confidence levels in the models, but scientists using coupled, transient simulations are now beginning to express growing confidence that current projections are plausible.

Transients and Surprises. However, such a very complicated coupled system like an ESM is likely to have unanticipated results when forced to change very rapidly by external disturbances like CO_2 and aerosols. Indeed, some of the transient models run out for hundreds of years exhibit dramatic change to the basic climate state (e.g., radical change in global ocean currents). Thompson and Schneider (1982) used very simplified transient models to investigate the question of whether the time evolving patterns of climate change might depend on the rate at which CO_2 concentrations increased. For slowly increasing CO_2 buildup scenarios, the model predicted the standard model outcome: the temperature at the poles warmed more than the tropics.

Any changes in equator-to-pole temperature difference help to create altered regional climates, since temperature differences over space influence large-scale atmospheric wind patterns. However, for very rapid increases in CO_2 concentrations a reversal of the equator-to-pole difference occurred. If sustained over time, this would imply difficult to forecast, transient climatic conditions during the century or so the climate adjusts toward its new equilibrium state. In other words, the harder and faster the enormously complex earth system is forced to change, the higher the likelihood for unanticipated responses. Or, in a phrase, the faster and harder we push on nature, the greater the chances for surprises—some of which are likely to be nasty.

Noting this possibility, the Summary for Policy makers of IPCC Working Group I concluded with the following paragraph:

> Future unexpected, large and rapid climate system changes (as have occurred in the past) are, by their nature, difficult to predict. This implies that future climate changes may also involve "surprises." In particular these arise from the non-linear nature of the climate system. When rapidly forced, non-linear systems are especially subject to unexpected behavior. Progress can be made by investigating non-linear processes and sub-components of the climatic system. Examples of such non-linear behavior include rapid circulation changes in the North Atlantic and feedbacks associated with terrestrial ecosystem changes.

Of course, if the Earth system were somehow less "rapidly forced" by virtue of policies designed to slow down the rate at which human activities modify the land surfaces and atmospheric composition, this would lower the likelihood of non-linear surprises. Whether the risks of such surprises justify investments in abatement activities is the question that Integrated Assessment (IA) activities are designed to inform (IPCC, 1996c). The likelihood of various climatic changes, along with estimates of the probabilities of such potential changes, are the kinds of information IA modelers need from earth systems scientists in order to perform IA simulations. We turn next, therefore, to a discussion of methods to evaluate the subjective probability distributions of scientists on one important climate change issue, the climate sensitivity.

Subjective Probability Estimation. Finally, what does define a scientific consensus? Morgan and Keith (1995) and Nordhaus (1994) are two attempts by non-climate scientists, who are interested in the policy implications of climate science, to tap the knowledgeable opinions of what they believe to be representative groups of scientists from physical, biological and social sciences on two separate questions: first the climate science itself and second impact assessment and policy. Their sample surveys show that although there is a wide divergence of opinion, nearly all scientists assign some probability of negligible outcomes and some probability of very highly serious outcomes, with one or two exceptions, like Richard Lindzen at MIT (who is scientist number 5 on Fig. 1 of Morgan and Keith).

In the Morgan and Keith study, each of the 16 scientists listed in Table 1 were put through a several hour, formal decision-analytic elicitation of their subjective probability estimates for a number of factors. Figure 1 shows the elicitation results for the important climate sensitivity factor. Note that 15 out of 16 scientists surveyed (including several IPCC Working Group I Lead Authors—I am scientist 9) assigned something like a 10 percent subjective likelihood of negligible (less than 1°C) climatic change from doubling of CO_2. These scientists also typically assigned a 10 percent probability for extremely large climatic changes—greater than 5°C, roughly equivalent to the temperature difference experienced between a glacial and interglacial age, but occurring some hundred times more rapidly. In addition to the lower probabilities assigned to the mild and catastrophic outcomes, the bulk of the scientists interviewed (with the one exception) assigned the bulk of their subjective cumulative probability distributions in the center of the IPCC range for climate sensitivity. What is most striking about the exception, scientist 5, is the lack of variance in his estimates—suggesting a very high confidence level in this scientist's mind that he understands how all the complex interactions within the earth-system described above will work. None of the other scientists displayed that confidence, nor did the Lead Authors of IPCC. However, several scientists interviewed by Morgan and Keith expressed concern for "surprise" scenarios—for example, scientists 2 and 4 explicitly display this possibility on Figure 1, whereas several other scientists implicitly allow for both positive and negative surprises since they assigned a considerable amount of their cumulative subjective probabilities for climate sensitivity outside of the standard 1.5 to 4.5 range. This concern for surprises is consistent with the concluding paragraph of the IPCC Working Group I Summary for Policymakers quoted above.

IPCC Lead Authors, who wrote the Working Group I Second Assessment Report, were fully aware of both the wide range of possible outcomes and the broad distributions of attendant subjective probabilities. After a number of sentences highlighting such uncertainties, the Report concluded: "nevertheless, the balance of evidence suggests that there is a discernible human influence on the climate." The reasons for this now-famous subjective judgment were many, such as the kinds of factors listed above. These include a well validated theoretical case for the greenhouse effect, validation tests of both model parameterizations and performance against present and paleoclimatic data, and the growing "fingerprint" evidence that suggests horizontal and vertical patterns of climate change predicted to occur in coupled atmosphere-ocean models has been increasingly evident in observations over that past several decades. Clearly, more research is needed, but enough is already known to warrant assessments of the possible impacts of such projected climatic changes and the relative merits of alternative actions to both mitigate emissions and/or make adaptations less costly. That is the ongoing task of integrated assessment analysts, a task that will become increasingly critical in the next century. To accomplish this task, it is important to recognize what is well established in climate theory and modeling and to separate this from aspect that are more speculative. That is precisely what IPCC (1996a) has attempted to accomplish.

III. Assessing The Impacts Of Climatic Change Projections

One of the most dramatic of the standard "impacts" of climatic warming projections is the increase in sea level typically associated with warmer climatic conditions. An EPA study used an unusual approach: combining climatic models with the subjective opinions of many scientists on the values of uncertain elements in the models to help bracket the uncertainties inherent in this issue. Titus and Narayanan (1996)—including teams of experts of all persuasions on the issue—calculated the final product of their impact assessment as a statistical distribution of future sea level rise, ranging from slightly negative values (i.e., a sea level drop) as a low probability outcome, to a meter or more rise, also with a low probability (see Fig 2). The midpoint of the probability distribution is something like half meter sea level rise by the end of the next century.

Since the EPA analysis stopped there, this is by no means a complete assessment. In order to take integrated assessment to its logical conclusion, we need to ask what the economic costs of various control strategies might be and how the costs of abatement compare to the economic or environmental losses (i.e. impacts or damages as they are called) from sea level rises. That means putting a value—a dollar value of course—on climate change, coastal wetlands, fisheries, environmental refugees, etc. Hadi Dowlatabadi at Carnegie Mellon University leads a team of integrated assessors who, like Titus, combined a wide range of scenarios of climatic changes and impacts but, unlike the EPA studies, added a wide range of abatement cost estimates into the mix. Their integrated assessment was presented in statistical form as a probability that investments in CO_2 emissions controls would either cost more than the losses from averted climate change or the reverse (e.g., Morgan and Dowlatabadi, 1996). Since their results do not include estimates for all conceivable costs (e.g., the political consequences of persons displaced from coastal flooding), the Carnegie Mellon group offered its results only as illustrative of the capability of integrated assessment techniques. Its numerical results have meaning only after the range of physical, biological and social outcomes and their costs and benefits have been quantified—a Herculean task. Similar studies have been made in Holland by a Dutch government effort to produce integrated assessments for policymakers. Jan Rotmans, who heads one of their efforts, likes to point out that such modeling of complex physical, biological and social factors cannot produce credible "answers" to current policy dilemmas, but can provide "insights" to policymakers that will put decisionmaking on a firmer factual basis (Rotmans and van Asselt, 1996). Understanding the strengths and weaknesses of any complex analytic tool is essential to rational policymaking, even if quantifying the costs and benefits of specific activities is controversial.

William Nordhaus, an economist from Yale University, has made heroic steps to put the climatic change policy debate into an optimizing framework. He is an economist who has long acknowledged that an efficient economy must internalize externalities (in other words, find the full social costs of our activities, not just the direct cost reflected in conventional "free market" prices). He tried to quantify this external damage from climate change and then tried to balance it against the costs to the global economy of policies designed to reduce CO_2 emissions. His optimized solution was a carbon tax, designed to internalize the externality of damage to the climate by increasing the price of fuels in proportion to how much carbon they emit, thereby providing an incentive for society to use less of these fuels.

Nordhaus (1992) imposed carbon tax scenarios ranging from a few dollars per ton to hundreds of dollars per ton—the latter which would effectively eliminate coal from the world economy. He showed that, in the context of his model and its assumptions, that these carbon emission fees would cost the world economy anywhere from less than 1 percent annual loss in Gross National Product to a several percent loss by the year 2100. The efficient, optimized solution from classical economic cost-benefit analysis is that carbon taxes should be levied sufficient to reduce the GNP as much as it is worth to avert climate change (e.g., the damage to GNP from climate change). He assumed that the impacts of climate change were equivalent to a loss of about 1 percent of GNP. This led to an "optimized" initial carbon tax of about five dollars or so per ton of carbon dioxide emitted. In the context of his modeling exercise, this would avert only a few tenths of a degree of global warming to the year 2100, a very small fraction of the 4°C warming his model projected.

How did Nordhaus arrive at climate damage being about 1 percent of GNP? He assumed that agriculture was the most vulnerable economic market sector to climate change. For decades agronomists had calculated potential changes to crop yields from various climate change scenarios, suggesting some regions now too hot would sustain heavy losses from warming whereas others, now too cold, could gain. Noting that the U.S. lost about one third of it's agricultural economy in the heat waves of 1988, and that agriculture then represented about 3 percent of the U.S. GNP, Nordhaus felt the typically projected climatic changes might thus cost the U.S. economy something like 1 percent annually in the 21st century. This figure was severely criticized because it neglected damages from health impacts (e.g., expanded areas of tropical diseases, heat-stress deaths, etc.), losses from coastal flooding or severe storms, security risks from boat people created from coastal disruptions in South Asia or any damages to wildlife, fisheries or ecosystems that would almost surely accompany temperature rises at rates of degrees per century as are typically projected. It also was criticized because his estimate neglected potential increases in crop or forestry yields from the direct effects of increased CO_2 in the air on the photosynthetic response of these marketable plants. Nordhaus responded to his critics by conducting a survey, similar to that undertaken by Morgan and Keith, but this time focused on the impacts of several scenarios of climatic change on world

economic product—including both standard market sector categories (e.g., forestry, agriculture, heating and cooling demands) and so-called non-market amenities like biological conservation and national security.

When Nordhaus surveyed the opinions of mainstream economists, environmental economists and natural scientists (I am respondent #10, in Nordhaus, 1994), he found that the former expressed a factor of 20 less anxiety about the economic or environmental consequences of climate change than the latter (see Fig.3—Scenario A is for 3°C warming by 2100 A.D. and Scenario C for 6°C by 2100 A.D.). However, the bulk of even the conservative group of economists Nordhaus surveyed considered there to be at least a 10 percent probability that typically projected climate changes could still cause economic damages worth several percent of gross world product (the current U.S. GNP is around five trillion dollars—about 20 percent of the global figure). And, some of these economists didn't include estimates for possible costs of "non-market" damages (e.g., harm to nature). One ecologist who did explicitly factor in non-market values for natural systems went so far as to assign a 10 percent chance of a hundred percent loss of GNP—the virtual end of civilization! While Nordhaus quipped that those who know most about the economy are less concerned, I countered with the obvious observation that those who know the most about nature are very concerned.

We will not easily resolve the paradigm gulf between the optimistic and pessimistic views of these specialists with different training, traditions and world views, but the one thing that is clear from both the Morgan and Keith and Nordhaus studies is that the vast bulk of knowledgeable experts from a variety of fields admits to a wide range of plausible outcomes in the area of global environmental change—including both mild and catastrophic eventualities—under their broad umbrella of possibilities. This is a condition ripe for misinterpretation by those who are unfamiliar with the wide range of probabilities most scientists attach to global change issues. The wide range of probabilities follows from recognition of the many uncertainties in data and assumptions still inherent in earth systems models, climatic impact models, economic models or their synthesis via integrated assessment models (see Schneider, 1997a,b). It is necessary in a highly interdisciplinary enterprise like the integrated assessment of global change problems that a wide range of possible outcomes be included, along with a representative sample of the subjective probabilities that knowledgeable assessment groups like the IPCC believe accompany each of those possible outcomes. In essence, the "bottom line" of estimating climatic impacts is that both "the end of the world" and "it is good for business" are the two lowest probability outcomes, and that the vast bulk of knowledgeable scientists and economists consider there to be a significant chance of climatic damage to both natural and social systems. Under these conditions—and the unlikelihood that research will soon eliminate the large uncertainties that still persist—it is not surprising that most formal climatic impact assessments have called for cautious, but positive steps both to slow down the rate at which humans modify the climatic system and to make natural and social systems more resilient to whatever changes do eventually materialize.

IV. Policy Implications

What Are Some Actions to Consider? Decisionmaking, of course, is a value judgment about how to take risks—gambling, if you will—in the environment-development arena. Despite the often bewildering complexity, making value choices does not require a Ph.D. in statistics, political science or geography to comprehend. Rather, citizens need simple explanations using common metaphors and everyday language that ordinary people can understand about the terms of the debate. Once the citizens of this planet become aware of the various tradeoffs involved in trying to choose between business-as-usual activities and sustainable environmental stewardship, the better will be the chances that the risk-averse common sense of the "average" person may be thrust into the decisionmaking process by a public that cares about its future and that of its planet, and knows enough not to be fooled by simple solutions packaged in slick commercials or editorials by any special interest.

What are the kinds of actions that can be considered to deal with global change problems like climate change. The following list is a consensus from a multi-disciplinary, business, university and government assessment conducted by the National Research Council in 1991. It is encouraging that this multi-discipline, ideologically diverse group (including economist Nordhaus, industrialist Frosch and climatologist Schneider) could agree that the United States, for example, could reduce or offset its greenhouse gas emissions by between 10 and 40 percent of 1990 levels at low cost, or at some net savings, if proper policies are implemented. Here is the Council's entire suggested list:

(1) Continue the aggressive phaseout of CFC and other halocarbon emissions and the development of substitutes that minimize or eliminate greenhouse gas emissions.

(2) Study in detail the "full social cost pricing" of energy, with a goal of gradually introducing such a system. On the basis of the principle that the polluter should pay, pricing of energy production and use should reflect the full costs of the associated environmental problems.

(3) Reduce the emissions of greenhouse gases during energy use and consumption by enhancing conservation and efficiency.

(4) Make greenhouse warming a key factor in planning for our future energy supply mix. The United States should adopt a systems approach that considers the interactions among supply, conversion, end use, and external effects in improving the economics and performance of the overall energy system.

(5) Reduce global deforestation.

(6) Explore a moderate domestic reforestation program and support international reforestation efforts.

(7) Maintain basic, applied, and experimental agricultural research to help farmers and commerce adapt to climate change and thus ensure ample food.

(8) Make water supply more robust by coping with present variability by increasing efficiency of use through water markets and by better management of present systems of supply.

(9) Plan margins of safety for long-lived structures to take into consideration possible climate change.

(10) Move to slow present losses in biodiversity.

(11) Undertake research and development projects to improve our understanding of both the potential of geoengineering options to offset global warming and their possible side-effects. This is not a recommendation that geoengineering options be undertaken at this time, but rather that we learn more about their likely advantages and disadvantages.

(12) Control of population growth has the potential to make a major contribution to raising living standards and to easing environmental problems like greenhouse warming. The United States should resume full participation in international programs to slow population growth and should contribute its share to their financial and other support.

(13) The United States should participate fully with officials at an appropriate level in international agreements and in programs to address greenhouse warming, including diplomatic conventions and research and development efforts.

This NRC (1991) assessment produced a remarkable list, considering the diversity of the participants' backgrounds and their varying ideological perspectives. But in the crucible of open debate that permeated that assessment activity, self-interest polemics and media grandstanding are incinerated. This group didn't assert that catastrophe was inevitable, nor that it was improbable. We simply believed that prudence dictates that "despite the great uncertainties, greenhouse warming is a potential threat sufficient to justify action now."

Integrated assessments of the policy options offered by the National Research Council Report are actively being pursued with a variety of models.

It is interesting that this comprehensive list of 13 recommendations from the National Research Council report still ignored two fundamental aspects: the desperate need for (1) an intelligent, non-polemical public debate about global change and (2) interdisciplinary public education that also teaches students about whole systems and long-term risk management, not only traditional areas of isolated specialization.

Environment and (or versus) Development? While the NRC report did acknowledge the importance of international dimensions of global change policymaking, it was still largely a developed country perspective. Developing countries often have very different perspectives. First of all, LDCs are struggling to raise literacy rates, lower death rates, increase life expectancy, provide employment for burgeoning populations and reduce local air and water pollution that pose imminent health hazards to their citizens and environments.

Protecting species or slowing climate change are simply low on their priority lists as compared to more mature economic powers like the OECD nations. It is ironic, even if understandable, that LDCs put abatement of global change disturbances so low on their priority lists despite the fact that nearly all impact assessments suggest that it is these very countries that are most vulnerable to climatic change, for example.

There is a phrase in economics known as "the marginal dollar." In our context it means that given all the complexity of interconnected physical, biological and social systems, climate abatement may not be perceived as the best place to invest the next available dollar so as to bring the maximum social benefit to poor coun-

tries. I have heard many representatives of LDCs exclaim that until poverty is corrected, preventable disease stamped out, injustice redressed and economic equity achieved, they will invest their precious resources on these priorities. My response has been that climatic changes can exacerbate all of those problems they rightly wish to address, and thus we should seek to make investments that both reduce the risks of climate change and help with economic development (transfer of efficient technologies being a prime example). It is a great mistake, I believe, to get trapped in the false logic of the mythical "marginal dollar," for it is not necessary that every penny of the next available dollar go exclusively to the highest priority problem whereas all the rest (particularly problems with surprise potential and the possibility of irreversible damages) must wait until priority one is fully achieved. To me, the first step is to get that marginal dollar cashed into small change, so that many interlinked priority problems can all be at least partially addressed. Given the large state of uncertainty surrounding both the costs and benefits of many human and natural events, it seems most prudent to address many issues simultaneously and to constantly reassess which investments are working and which problems—including global change—are growing more or less serious.

It takes resources to invest, of course, and since the bulk of available capital is in developed countries, it will require international negotiations—"planetary bargaining" it has been called—to balance issues of economic parity and social justice with environmental protection. Such negotiations are underway under U.N. auspices, and will likely take many years to work out protocols that weigh the diverse interests and perceptions of the world's nations.

There is a lively debate among economists, technologists and environmentalists about what are the most cost-effective strategies for abating carbon emissions which also can reduce potential impacts of climatic changes to below the undefined "dangerous" levels referred to in the Framework Convention on Climate Change language. Most economists argue that some policy to "internalize the externality" of potential climate damage is already appropriate, reflecting the recommendations already published by the National Research Council in 1991. Environmentalists usually argue that major efforts to spur immediate abatement of carbon emissions are necessary if climatic changes less than one more degree Celsius are to likely be avoided (which they typically define as "dangerous"). Most economists, on the other hand, often argue that new technologies will be able to accomplish carbon abatement more cheaply in the future as such technologies are discovered and deployed (Wigley et al, 1996). Thus, their logic suggests that a cost-effective time profile of abatement would be to postpone most carbon reductions until later in the 21st century. This seemingly implacable debate will echo in Kyoto chambers, I am sure, in December 1997.

My colleague, the Stanford University economist Lawrence Goulder, and I have used state-of-the-art economic modeling tools to study this debate, and conclude that both the stereotypical environmentalist (who argue to abate now) and economist positions (abate later) are actually not incompatible, but complimentary! We show (please see the Appendix in which our submitted Commentary to Nature magazine is reproduced) that although the economist view that future abatement is likely to be cheaper is probably correct, so too is the environmentalist argument that current actions are urgently needed, since such technologies referred to in economic cost-effectiveness studies won't simply invent themselves. In other words, policy actions to help induce technological changes are needed now in order to bring about a profile of cost-effective abatement in the decades ahead. We also address the relative economic efficiency of alternative policy instruments: contrasting carbon taxes versus research and development subsides. Although we recognize the political reluctance of many to embrace any new taxes, in truth, most economic analyses show that a fee for the use of the atmosphere (currently a "free sewer") will reduce incentives to pollute, increase incentives to develop and deploy less polluting technologies, and can be more economically efficient than other policies—particularly if some of the revenues generated by a carbon tax were recycled back into the economy. R&D subsidies can be economically efficient, our conventional economic analyses suggest, to the extent that current R&D markets are already subsidized or otherwise not optimally efficient—a likelihood.

Therefore, it is my personal view that all parties should recognize that potential damages to a global commons like the Earth's climate are not mere ideological rhetoric, nor are solutions necessarily unaffordable. Moreover, "win-win" solutions in which economic efficiency, cost-effectiveness and environmental protection can happily co-exist are possible—if only we put aside hardened ideological positions.

V. Personal Observations On The Global Warming Media Debate

A very intense, too-often personal and *ad hominem,* media debate has attended the global warming problem in the past 5 years. As a participant in this process, I can attest to the frustration one experiences in seeing a complex scientific problem with many policy implications often trivialized into an ideological boxing match in which polar extremes are pitted against each other and the work of the vast bulk of the knowledgeable community is marginalized. A baffling array of claims and counter claims appears, particularly in op-ed pieces, and a general state of public confusion is fostered. It is my belief that this confusion does not reflect the ordered state of knowledge, in which many aspects of the climate change issue enjoy strong consensual views, other aspects are considered plausible, whereas yet others are clearly (to insiders at least) highly speculative. Public dialog would be much richer if we all strove to separate out what is well known from what is speculative, an effort not attempted often enough in most public accounts of the issue. How is this best accomplished?

For 20 years the scientific community, or at least the broad cross section scientific community represented by the deliberations of the National Research Council, IPCC and other international assessment groups, have suggested that if CO_2 were to double and be held fixed, then at equilibrium (i.e. the change in steady state after a few hundred years) the earth's temperature would warm up some one and a half to four and a half degrees centigrade—the uncertainty, as noted earlier, in this climate sensitivity range largely being associated with the well recognized processes that we treat crudely in our climate models, mostly clouds and water vapor. The reason that very few scientist set the climate sensitivity range above four and a half degrees or below one and a half degrees is primarily because of natural experiments such as ice ages, volcanoes and seasonal cycles, as well as other technical questions dealing with theory and modeling (see IPCC 1996a for details). Nevertheless, a few have asserted, some with very high confidence, that global warming from CO_2 doubling would only cause a few tenths of a°C equilibrium temperature rise, and even have argued that certain processes that they can name, but cannot demonstrate to have global scale effects, would be responsible for this diminishing effect (e.g., Lindzen, 1990). Such debates (e.g., see Schneider, 1990) are very difficult for the lay public to penetrate, and even for relatively skilled but still non-professional observers, they are hard to follow. It is for such reasons that groups like the National Research Council or The World Meteorological Organization and the United Nations Environment Program have called a community of scientists holding a spectrum of views, but all knowledgeable in the basic art, to meet together to debate the relative merits of various lines of evidence and to provide assessments which give the best guess as well as a judgment for the ranges of uncertainty of a variety of climate changes, as well as their potential impacts on environment and society and the costs of mitigation from alternative policies. Indeed, the Intergovernmental Panel on Climate Change (IPCC 1996a, b, and c) is now the premier such assessment activity and represents the effort of hundreds of directly involved scientists and thousands of indirectly involved scientists, industrialists, NGO's or policymakers who serve as reviewers and commentators.

The IPCC Peer Review Processes. Let me contrast the IPCC process with that of some of its critics. In July 1996 an extraordinary meeting of about six dozen climate scientists from dozens of countries took place. It was the third installment of a process to write a Second Assessment Report for the IPCC. This meeting, in Asheville, North Carolina, was designed to make explicit the points of agreement and difference among the scientists over exceedingly controversial and difficult issues, including the signal detection and attribution chapter—the most controversial. Chapter 8 was controversial since new lines of evidence had been brought to bear by three modeling groups around the world, each suggesting a much stronger possibility that a climate change signal has been observed and that its pattern (or fingerprint) is much closer matched to anthropogenic caused changes than heretofore believed. Scientists are by nature a skeptical lot, and typically submit their work for peer review before publishing. When scientists have new ideas or new tests, as the dozen or so representing these modeling groups in fact had, they typically write a journal article and submit it for publication. The journals, peer reviewed of course, typically send the article out to two or three peers, who write anonymous reviews, (unless the reviewers have the courage to confess as I, the editor of the journal Climatic Change, encourage my reviewers to do). The authors then rewrite their article in response to the reviewers and the editor serves as referee. The process usually goes back and forth several times with several revised drafts of the article until a suitable compromise is achieved among reviewers, authors and the editor.

Contrast this normal journal peer review process in which a few people are involved, with what happened in Asheville in 1995 at the IPCC's third workshop. Ben

Santer from Lawrence Livermore National Lab, who had assembled the results of a number of modeling groups and was the first author of the submitted manuscript (Santer et al, 1996) on climate signal detection and the Convening Lead Author of Chapter 8 of the IPCC report (the controversial IPCC chapter on signal detection and attribution), presented the results of his group's effort not to just the half dozen Lead Authors of Chapter 8, as is typical in IPCC meetings, but to the entire assembled scientific group at Asheville. Not only did Santer have to explain the work of him and his colleagues (many of whom were there) to his most knowledgeable peers, but also to scores of others from communities as diverse as stratospheric ozone experts like Susan Solomon and Dan Albritton, to satellite meteorologists like John Christy or biospheric dynamics experts such as Jerry Melillo. Climatologists such as Tom Karl or myself were also present, along with heads of weather services and other officials from several countries who served on the IPCC's assessment team as a member of the scientific delegations of the various nations. Not everybody was equally knowledgeable in the technical details of the debate, of course, but even these less familiar participants served an essential role: of witnesses to the process of honest, open debate. Perhaps only twenty-five percent of those assembled had truly in-depth knowledge of the full range of details being discussed. However, all understood the basic scientific issues and most know how to recognize slipshod work—to say nothing of a fraud or a "scientific cleansing"—when they see it. This remarkable session lasted for hours, was occasionally intense, always was cordial, and never turned polemical. As a result, words for Chapter 8 were changed, ideas and concepts altered somewhat, but by and large basic conclusions were unchanged because the vast bulk of those assembled (and no one proclaimed to the contrary) were convinced that the carefully hedged statements the lead authors proposed were, in fact, an accurate reflection of the state of the science based upon all available knowledge—including the new results. This was not only peer review, but this was peer review ten times normal! As the editor of a peer review journal it would be inconceivable for me to duplicate this process, as I have to hope that a few referees and myself can serve the peer reviewing role half as well as this remarkable, open process at Asheville. Moreover, after the Asheville meeting there were two more IPCC drafts written and reviewed by hundreds of additional scientists industrialists, policymakers, and NGO's from all over the globe.

Contrast this open IPCC process then, to the harsh critics of the IPCC, alleging "scientific cleansing", "herd mentality", and first presenting their detailed technical counter arguments in such "refereed scientific literature" as the editorial pages of the Wall Street Journal (Singer 1996, Seitz 1996,). Some had the temerity, although I do not understand how they could do it with a straight face, to allege that Chapter 8 conclusions were all based upon non peer reviewed work, despite the fact that the Asheville process was ten times normal peer review, to say nothing of the hundreds of scientific reviewers of the next draft of the IPCC report that followed. In the wake of all these reviews, textual alterations needed to be made, and these were minor, but were done over the course of time. The last round of changes were made by the Convening Lead, Ben Santer. Some interests subsequently alleged that these minor changes dramatically altered the report and, with no evidence, asserted they were politically motivated ("scientific cleansing" one charged—and launched a vicious personal attack on one of the least political, most cautious scientists, Ben Santer). Any honest evaluation will reveal that this irresponsible charge—published in the unrefereed opinion pages of a business daily—is utterly absurd. In fact, the most famous line in the IPCC report (that there is a "discernible" human effect on climate) appeared as one sentence in a short paragraph that was 80 percent caveats! The IPCC report essentially "drips" with caveats.

Moreover, the "discernible" line is not a radical statement, as it reflects a lowest common denominator consensus view of the vast bulk of people exposed to the evidence. It does not assert climate signal detection to be proven beyond any doubt, nor do I or any other responsible scientists I know of make such assertions. Nor can such evidence of human effects be dismissed as wholly random at a very high probability by responsible scientists—except perhaps in the opinions section of some newspapers. To ignore such contrarian critics would be inappropriate, I agree. However, to give them in news stories comparable weight to a hundred-scientists, thousand-reviewer document, as if somehow a small minority of scientists who are skeptical deserve equal weight, without informing the readership or viewership that the contrarians represent a tiny minority, is to mislead a public who cannot be expected to look up for themselves the relative weights of conflicting opinions. And to publish character-assassinating charges of "scientific cleansing" without checking the facts is simply unethical—at least in any system of ethics I respect.

VI. Concluding Remarks

A condensed summary of the principal conclusions I would like to draw is as follows, beginning with the more narrowly technical issues and proceeding to broader generalizations about impacts, uncertainties and policy choices:

Hierarchy of models. A hierarchy of models, ranging from simple zero or one-dimensional, highly parameterized models up to coupled three-dimensional models that simulate the dynamics and thermodynamics of connected physical and biological sub-systems of the earth-system are needed for climatic effects assessment. The simpler models are more transparent—allowing cause-and-effect processes to be more easily traced—and are much more tractable to construct, run and diagnose, whereas multi-dimensional, dynamical models can provide geographic and temporal resolution needed for regional impact assessments and—hopefully—provide more realistic and detailed simulations, even if at much higher costs for construction, computation, diagnosis and interpretability. Since the real climate system is undergoing a transient response to regionally heterogeneous (patchy) forcings (e.g., aerosols and greenhouse gasses combined, which both vary over time and space), eventually it will be necessary to run fully coupled three-dimensional earth systems models in order to "hand off" their results to a variety of regional impact assessment models. In the interim, lower resolution "simple" climate models can be hybridized into more comprehensive models to produce hybrid estimates of time-evolving regional patterns of climatic changes from a variety of emissions and land use change scenarios. Such estimates may be instructive to policymakers interested in the differential climatic impacts of various climate forcing scenarios and/or various assumptions about the internal dynamics of both climate and impact models.

Sensitivity studies are essential. It is unlikely that all important uncertainties in either climatic or impact models will be resolved to the satisfaction of the bulk of the scientific community in the near future. However, this does not imply that model results are uninformative. On the contrary, sensitivity analyses in which various policy-driven alternative radiative forcing assumptions are made can offer insights into the potential effectiveness of such policies in terms of their differential climatic effects and impacts. Even though absolute accuracy is not likely to be assured for the foreseeable future, considerable precision concerning the sensitivity of the physical and biological sub-systems of the earth can be studied via carefully planned and executed sensitivity studies across a hierarchy of models.

Validation and testing are required. Although it may be impractical, if not theoretically impossible, to validate the precise future course of climate given the uncertainties that remain in forcings, internal dynamics and unpredictable surprise events, many of the basic features of the coupled physical and biological sub-systems of the earth can already be simulated to a considerable degree. Testing models against each other when driven by the same sets of forcing scenarios, testing the overall simulation skill of models against empirical observations, testing model parameterizations against high resolution process models or data sets, testing models against proxy data of paleoclimatic changes and testing the sensitivity of models to radiative forcings of anthropogenic origin by computing their sensitivity to natural radiative forcings (e.g., season radiative forcing, volcanic dust forcing, orbital element variation forcings etc.) comprise a necessary set of validation-oriented exercises that all modelers should agree to perform. Similarly, impacts models should also be subjected to an analogous set of validation protocols if their insights are to gain a high degree of credibility.

Subjective probability assessment. In addition to standard simulation modeling exercises in which various parameters are specified or varied over an uncertainty range, formal decision-analytic techniques can be used to provide a more consistent set of values for uncertain model parameters or functional relationships. The embedding of subjective probability distributions into climatic models is just beginning (e.g., Titus and Narayanan, 1996), but may become an important element of integrated assessment modeling in future generations of model building (e.g., see the discussion of the hierarchy of integrated assessment models in Schneider, 1997b).

"Rolling reassessment." It is obvious that the projection of climatic effects and related impacts will continue to change as the state-of-the-art in both kinds of models improves over the next few decades. Therefore, the most flexible management possible of a global commons like the Earth's climate seems a virtual necessity, since the potential seriousness of the problem—or even the perception of that seriousness—is virtually certain to change with new discoveries and actual climatic and other environmental or social events. Therefore, a series of assessments of climatic effects, related impacts, and policy options to prevent potentially dangerous impacts will be needed periodically—perhaps every 5 years as IPCC has chosen for the repeat period of its major Assessment Reports that treat climatic effects, impacts and policy issues as separable assessments. It seems important that whatever policy in-

struments are employed (to either mitigate anthropogenic forcings or help reduce damage from projected climatic effects) be flexible enough to respond quickly and cost-effectively to the evolving science that will emerge from this rolling reassessment process.

Consider surprises and irreversibility. Given the many uncertainties that still attend most aspects of the climatic change and impacts debate, priority should be considered for those aspects which could exhibit irreversible damages (e.g., extinction of species whose already-shrinking habitat is further stressed by rapid climatic changes) or for which imaginable "surprises" have been identified (e.g., alterations to oceanic currents from rapid increases in greenhouse gasses). For these reasons, management of climatic risks needs to be considered well in advance of more certain knowledge of climatic effects and impacts.

"Win-win" strategies. Economically efficient, cost-effective and environmentally sustainable policies have been identified and others can be found to help induce the kinds of technological innovations needed to reduce atmospheric emissions in the decades ahead. Some mix of emissions "cap and trade", carbon taxes with revenue recycling, or technology development incentives can provide "win-win" solutions if all parties to the environment-development debate would lower the intensity of their ideological preconceptions and work together for cost-effective and equitable measures to protect the global commons.

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Table 1: Experts interviewed in the study. Expert numbers used in reporting results are randomized. They do not correspond with either alphabetical order or the order in which the interviews were performed.

James Anderson, Harvard University	Michael MacCracken, US Global Change Research Program
Robert Cess, State University of New York at Stony Brook	Ronald Prinn, Massachusetts Institute of Technology
Robert Dickinson, University of Arizona	Stephen Schneider, Stanford University
Lawrence Gates, Lawrence Livermore National Laboratories	Peter Stone, Massachusetts Institute of Technology
William Holland, National Center for Atmospheric Research	Starley Thompson, National Center for Atmospheric Research
Thomas Karl, National Climatic Data Center	Warren Washington, National Center for Atmospheric Research
Richard Lindzen, Massachusetts Institute of Technology	Tom Wigley, University Center for Atmospheric Research/National Center for Atmospheric Research
Syukuro Manabe, Geophysical Fluid Dynamics Laboratory	Carl Wunsch, Massachusetts Institute of Technology

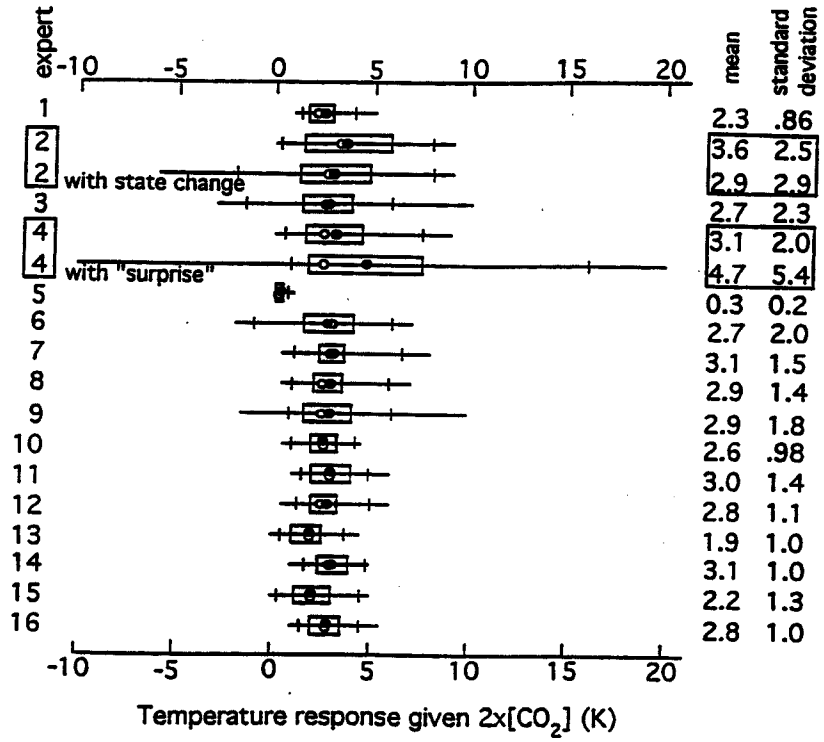

Figure 1 Box plots of elicited probability distributions of climate sensitivity, the change in globally averaged surface temperature for a 2x[CO_2] forcing. Horizontal line denotes range from minimum to maximum assessed possible values. Vertical tick marks indicate locations of lower 5 and upper 95 percentiles. Box indicates interval spanned by 50% confidence interval. Solid dot is the mean and open dot is the median. The two columns of numbers on right hand side of the figure report values of mean and standard deviation of the distributions.

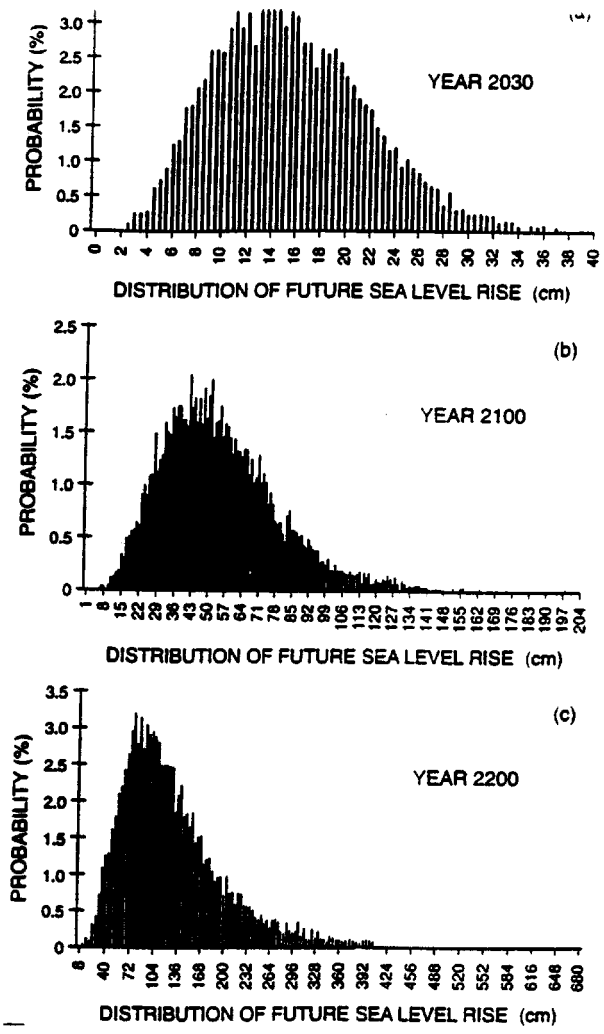

FIGURE 2

Rather than pretend we can know precisely what will happen to climate in the twenty-first century, it is more appropriate to express future scenarios as a probability distribution. Here, James Titus and V. Narayanan have compounded a range of possible CO_2 emission estimates with a range of possible CO_2 concentrations and used the latter to calculate a range of possible climatic changes (sea level rise, in this case). While the probabilities calculated for each specific outcome cannot be taken as quantitatively reliable, the overall shape of the graphs and magnitudes of the changes are representative of state-of-the-art assessments.

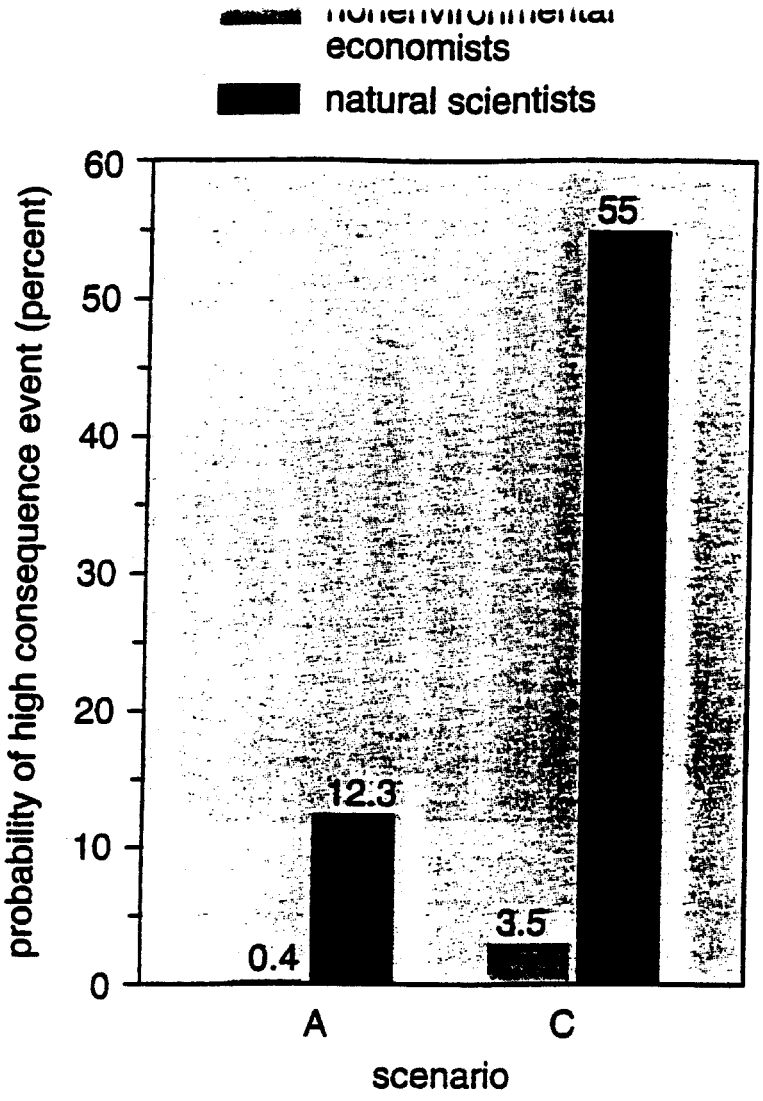

Figure 3. Difference in academic discipline separated those making high estimates of the economic impacts from global warming from those who were comparatively unconcerned. Natural scientists' estimates were 20 to 30 times higher than mainstream economists'.

APPENDIX

(Commentary resubmitted to Nature *after initial round of peer review in June 1997)*

Achieving Carbon Dioxide Targets Cost-Effectively: What Needs To Be Done Now?

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I. Introduction

There has been a great deal of discussion about potential ways to reduce the rate of atmospheric accumulation of carbon dioxide (CO_2) and other greenhouse gases. This commentary aims to clarify key economic issues related to the debates about the timing of efforts to reduce CO_2 emissions, and about what policies might be involved in such efforts. We will argue that:

(1) It is crucial to distinguish between the timing of *emissions abatement* and the timing of *abatement policy*. Although there are compelling arguments for relatively small amounts of CO_2 mitigation in the near term relative to the amount of abatement in the distant future, the emphasis on delayed abatement does not justify the absence of policy action in the present or very near future. To the contrary, near-term abatement policy is crucial to bringing about low-cost reductions in CO_2 emissions, even when most of those reductions occur in the distant future.

(2) A carbon tax appears to be the most economically efficient and administratively flexible instrument to employ as part of current policy action.

(3) Under a range of plausible economic assumptions, a carbon tax is a better instrument for generating a cost-effective abatement profile than subsidies to R&D in alternative, low-carbon sources of energy. However, under some circumstances the most cost-effective policy is a combination of carbon tax and an R&D subsidy, where both the tax and subsidy are implemented in the near term.

II. Postponing Abatement Does Not Mean Postponing Policy

This journal recently published a widely cited and instructive article by Wigley, Richels and Edmonds[1] on the appropriate timing of emissions abatement. Wigley *et al.*

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examined several alternative mitigation pathways that culminated in the same long-term concentration of CO_2, and concluded that in general overall abatement costs are kept to a minimum when the bulk of CO_2 abatement takes place in the more distant future rather than in the near term. The article offered four explanations for their conclusion. The first is the positive return on capital: abatement costs in the distant future can be discounted more than nearer term abatement costs. The second is the idea that the capital stock for energy production and end use can be long-lived, which implies that delayed abatement allows orderly replacement of expensive production assets with less carbon or energy intensive new technologies after the older stock has surpassed its economic lifetime. The third is technological progress: over time, new technologies that are less carbon- and energy-intensive are discovered and developed, and this means that the "availability of low-carbon substitutes will probably improve and their costs reduce over time." Wigley *et al.* also use a fourth argument, namely that carbon emitted sooner is exposed longer to natural removal processes than carbon emitted later, and thus delayed abatement permits a larger cumulative emissions total to produce the same long-term concentration target.

The main idea expressed in Wigley *et al.* -- that society can economize on the costs of achieving future concentrations targets by doing more abatement in the future than in the short term -- has won many adherents. However, others (e.g., Ha-Duong, Grubb, and Hourcade[2]) contend that *delaying* current abatement efforts may be costly, since current abatement efforts can be a crucial catalyst for generating the technological progress that ultimately leads to lower costs of abatement.

Much of this disagreement can be overcome if one distinguishes between *emissions abatement* and *abatement policy*. While there are strong arguments to justify concentrating the bulk of emissions abatement in the more distant future, we offer below comparably compelling arguments for implementing, in the near term, government policies that set in motion the sorts of economic adjustments necessary to bring about low-cost reductions in emissions.

III. Introducing a Carbon Tax Today Helps Produce a Cost-Effective Time Profile of Emissions Abatement

Climate-related damages from accumulation of CO_2 represent an "externality" that is not captured in the price of carbon-based fuels.[3] In the absence of government intervention, the market prices of these fuels do not include this important element of social cost. The policy of a carbon tax deals with this problem directly: if set

appropriately, this tax helps market prices better reflect the full social cost. This gives purchasers of fuels the incentive to conserve on use of these fuels and to substitute other inputs. In addition, because the tax will cause prices of carbon-intensive consumer goods to rise relative to the prices of other goods, it gives individual consumers the incentives to alter their purchases and to rely more on less carbon-intensive goods and services, and it gives producers incentives to develop and deploy alternatives.

Of course, other policies could be used to discourage or restrict the use of carbon-intensive fuels. These include direct limits or caps on fuel use, fuel-efficiency standards, and mandated technologies or equipment. An extensive economics literature compares these alternative instruments with the carbon tax.[4,5] This literature tends to embrace the carbon tax as the most economically efficient and flexible instrument, because it economizes on policy makers' information requirements, provides dynamic incentives (discussed below), is relatively inexpensive to administer, and is relatively easy to adjust in response to new information (a virtual certainty in climate-assessment) in comparison with technology mandates. Moreover, a carbon tax would bring in government revenue that could be used to finance cuts in ordinary income taxes, thereby helping avoid the inefficiencies associated with the disincentives to work or to save implied by income taxes. Recent work indicates that this ability to generate revenues makes the carbon tax much more efficient relative to quantity limits on carbon use.[6]

It is important to recognize that an appropriately scaled carbon tax also helps insure the most efficient time-profile for abatement. We concur with Wigley *et al.*'s argument that cost-effectiveness requires that the bulk of carbon emissions abatement (relative to the path of emissions under an unconstrained business-as-usual scenario) occur in the future rather than the present. *But concentrating abatement in the future does not justify avoiding carbon taxes in the near term.* Economic analysis indicates that carbon tax rates should be set according to the "marginal environmental damage" from CO_2 emissions. Most analyses indicate that this implies a carbon tax of rising rates through time[3,7,8]. Rising tax rates help encourage ever-increasing amounts of abatement. Moreover, even a *constant* carbon tax rate, though less than optimal from the point of view of economic efficiency, is consistent with a rising time-profile for abatement. This reflects the idea that, as new technological options for emissions- (or fuel-) abatement are discovered and implemented, the profit-maximizing amount of emissions abatement expands -- even if the tax rate is constant. Thus, there is no contradiction between the

current introduction of carbon taxes and the cost-effective time profile for emissions abatement.

Moreover, introducing the carbon tax in the near term is a key ingredient to speeding up the technological change that justifies more future abatement relative to near-term abatement. By making the use of carbon-based fuels more expensive, a carbon tax provides incentives to engage in R&D aimed at the discovery and development of alternative energy supply and energy end-use options. While the *rationale* for a carbon tax is the need to incorporate into the price of carbon-based fuels the externalities associated with carbon use, an important bi-product of this tax is the stimulation of R&D and (presumably) technological progress in alternative energy sources. As emphasized by Ha-Duong, Grubb, and Hourcade, a carbon tax can also stimulate technological change by promoting "learning-by-doing." In the climate-change context, this means that experience with processes that reduce CO_2 emissions can generate new knowledge as to how to reduce emissions more cheaply. In our view, the carbon tax is a useful vehicle for exploiting this phenomenon. By introducing the tax (now), one promotes greater experience with alternatives to conventional fuels, which in turn sparks technological innovation.

IV. R&D Subsidies vs. Carbon Taxes

Does the carbon tax's ability to stimulate R&D mean there is no justification for introducing an R&D subsidy as part of climate-change policy? A general economic principle is that governments should apply the policy instrument most closely related to the particular "market failure" at hand. As noted, the central market failure here is the climate-damage externality associated primarily with combustion of carbon-based fuels, and that the carbon tax is the policy instrument that is directly oriented to that failure. A subsidy to R&D does not directly deal with this market failure, because it does not directly alter the prices of carbon-based fuels. If there were no other market failures to be concerned about, an R&D subsidy would be unnecessary: the carbon tax alone would be up to the task of reducing in a cost-effective manner the accumulation of CO_2.

However, there is a *second* market failure to consider in connection with climate policy -- failure in the market for R&D. It is well known that private investments in research and development may generate "spillover benefits" that are enjoyed by parties other than the party making the investment. (For example, when an electronics firm invests in R&D in new production methods, the fruits of that investment may be enjoyed

in part by other firms.) Not all knowledge can be kept as private knowledge. Economic theory indicates that, under these circumstances, firms tend to under invest in R&D, mainly because they do not take into account the full social value (including the spillover benefits) when they make the investments. A government subsidy to R&D can correct this market failure. The ideal subsidy would lower the firm's cost of R&D enough to cause the firm to expand its investment in R&D to the socially optimal level.

Does this theoretical argument imply that a carbon tax should be accompanied by an R&D subsidy to alternative, low-carbon or carbon-free energy supplies? It depends. The theory suggests that an R&D subsidy is appropriate wherever there are significant spillovers. If such spillovers arise in connection with virtually all industrial investments in R&D, then the most economically efficient policy response is not a specific R&D subsidy to investments in alternative energy, but rather a broad-based subsidy applicable to R&D investments by a wide spectrum of industries. On the other hand, if such spillovers are particularly significant for investments in alternative energy supplies, then there is a basis for a more specific R&D subsidy, that is, a subsidy targeted to investments in R&D in alternative energy. The resolution of this issue requires further empirical investigation; the evidence to support a targeted subsidy, so far, is scanty. Public policy needs to proceed cautiously here: while there are strong theoretical and empirical reasons to support a carbon tax, the efficiency case for a targeted R&D subsidy is less clear.

[Table 1 about here]

Results from our economic simulation model for the U.S.[9] are in accord with the theoretical ideas just mentioned. (To our knowledge, ours is the only large-scale general equilibrium economic model that treats incentives to invest in R&D, knowledge-spillovers, and the functioning of R&D markets; hence it is uniquely suited to investigate these issues.) The particular numbers are illustrative, and we emphasize the qualitative insights from the results, not the specific numbers. Table 1 shows the costs of reducing cumulative CO_2 emissions by 15 percent over the 100-year period beginning 1995 (the initial simulation year). Panel A of this table evaluates these costs when the model includes no spillovers from R&D investments. In this situation, the cheapest way to attain the target is through a carbon tax alone. In the second panel, we evaluate these costs under the assumption that there are significant spillovers from investments in R&D

by the "alternative energy" industry (that is, the non-carbon-based fuel industry). In this case, the combination of carbon tax and R&D subsidy to alternative energy represents the most cost-effective way to attain the abatement target. This combination is cheaper that the combination of carbon tax and *broad* subsidy to all investments in R&D. Panel C considers the case where *all* investments in R&D involve significant spillovers. In this case, the least-cost policy involves a combination of carbon tax and *broad* subsidy to R&D. In no case does the R&D subsidy by itself offer the cheapest way to meet the target reduction in cumulative emissions; indeed, when the R&D subsidy is introduced alone, the costs of meeting the target are several times higher than in the other cases. These results support the idea that a carbon tax is essential for cost-effective reductions of CO_2 emissions, and that this tax should be accompanied by an R&D subsidy only to the extent that there are spillover benefits from R&D.

A caveat is in order. If R&D markets are already highly inefficient (e.g., distorted by prior subsidies or taxes), then gauging the costs of *new* R&D subsidies applied to low-carbon sources of energy becomes more complicated. Depending on the array of pre-existing subsidies, the costs of a combination of carbon tax and R&D subsidy might be higher or lower than what is suggested in Table 1. These qualifications do not contradict the general principle that to maximize economic efficiency R&D subsidies are warranted only insofar as there are spillovers in R&D markets.

V. Two Further Considerations

Political Considerations

We have emphasized that a carbon tax is a crucial instrument for producing a cost-effective abatement path. However, this policy is likely to be less popular than subsidies to R&D in new energy technologies. Producers tend to abhor taxes and embrace subsidies, for obvious reasons. But a policy consisting only of R&D subsidies would not likely reduce emissions in the lowest-cost manner. It is also worth noting that while an R&D subsidy is more favorable to producers, a carbon tax is more attractive to general taxpayers (although some low income groups express concern about its potential regressivity). An R&D subsidy needs to be financed through other tax revenues; in contrast, under a carbon tax policy the government can "recycle" carbon tax revenues, that is, use the revenues to finance cuts in individual income taxes, to the benefit of

general taxpayers (including lower income groups). Balanced discussions of policy options require attention to these impacts on the tax-paying public.

We have concentrated our analyses on issues of cost-effectiveness and economic efficiency. Of course, in the political arena there are advocates for other policy principles, such as the precautionary principle or the principle of stewardship. Our purpose here is not to debate the relative merits of alternative criteria for policy choices, but simply show that a "do-nothing" policy is difficult to justify, even according to a policy criterion endorsed by most economists.

Uncertainty

Thus far we have ignored a key issue related to the policy problem: uncertainty. We cannot address this issue in detail here. Some claim that current policy action is premature, given the uncertainties about the likely extent of climate change and the associated damages. Others maintain that the postponement of policy action could necessitate more substantial, and much more costly, future action if such action were ultimately required. Analytical work on this issue indicates that current policy action remains worthwhile, despite the uncertainties, provided that there are not prohibitively high "sunk costs" of introducing the policy in question[10,11]. An attraction of a carbon tax policy is that it involves very minimal sunk costs, which suggests that near-term action is warranted. Moreover, it is flexible enough to allow adjustments as new information as to of the seriousness of climate change and the effectiveness of policy tools becomes available.[12]

VI. Conclusions

It may be cost-effective to parcel most of the *abatement* of CO_2 in the longer term rather than the near term. But we emphasize that current *policy action* is needed to bring about a cost-effective time profile of abatement, even if most abatement takes place in the future. We would argue that a carbon tax (or some other flexible policy that directly confronts the evolving climate-change externality from fossil-fuel combustion) is an essential element of greenhouse policy. An R&D subsidy may be justified as complement to a carbon tax when there are R&D market failures. But the case for the subsidy (in terms of economic efficiency) rests primarily on spillover benefits from R&D rather than on the prospect of environmental damages from the atmospheric buildup of CO_2.

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Table 1

Costs of Achieving 15 Percent Reduction in Cumulative CO_2 Emissions Over Period 1995-2095

(Percentage Reduction in Present Value of GDP)

Scenario	Carbon Tax Alone	Targeted R&D Subsidy Alone	Carbon Tax Plus Targeted R&D Subsidy		Carbon Tax Plus Broad R&D Subsidy	
			subsidy rate = 1%	subsidy rate = 5%	subsidy rate = 1%	subsidy rate = 5%
A. No Spillovers from R&D	.416	1.355	.427	.444	.483	.523
B. Spillovers from R&D by Alternative Energy Industry (only)	.382	1.294	.366	.350	.380	.412
C. Spillovers from R&D Investment by All Industries	.433	1.323	.441	.455	.401	.319

Note: All simulations involve carbon tax rates that increase at a rate of 5 percent annually through the year 2075 and remain constant thereafter. In each scenario, the carbon tax profile is the lowest path of (rising) tax rates that leads to the desired reduction in cumulative emissions.

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RESPONSES BY DR. STEPHEN H. SCHNEIDER TO ADDITIONAL QUESTIONS FROM SENATOR BAUCUS

Question 1. During the hearing, Dr. Barron stated that our strategies to address increasing concentrations of greenhouse gases should be adaptive in nature. In your opinion, what would be the most important adaptation strategies to pursue?

Response. I agree with Dr. Barron that adaptive strategies are the most sensible. The reason I feel that they are sensible, as I also pointed out in written and oral testimoneys, is that it is very likely that further information on both climatic effects and impacts is likely to change our perceptions of the damages that climate could cause to environment and society, as well as the costs of mitigating those damages as new technologies are invented and implemented. Therefore, whatever policy instruments we adopt should have the maximum flexibility to be able to take advantage of, what I called in my written testimony, "rolling re-assessment." That is, every five or so years some groups (like the IPCC) will produce the assessments, and the state of knowledge so assessed might indicate more serious (or less serious) concern over climate change than previous assessments. Therefore, policy instruments that are most flexible will allow the highest degree of adaptive management. In my personal view, although I recognize that political realities (currently in the United States at least) stand in its way, a carbon tax is probably the most flexible instrument (see the Appendix to my written testimony, which contains the commentary, now accepted, for Nature magazine by Professor Larry Goulder and myself defending the flexibility and economic efficiency aspects of a carbon tax as opposed to other carbon policy instruments). But regardless of whether a carbon tax, cap and trade arrangements, R&D subsidies or other instruments are the ultimate policies of choice, minimizing "hardwiring" would seem to me the best strategy.

There are other areas where I think adaptive measures should also be considered. I have long advocated "anticipatory adaptation" as one of the responses to the possibility of negative effects of climatic changes. For example, a new water project could well increase the height of a dam, the width of a channel, or the amount of free coastline before expensive infrastructure would be allowed to be built, all in anticipation of the not unlikely possibility of increased extremes of drought and flood or sea levels. Building extra margins of safety into currently planned or future infrastructure is usually very inexpensive relative to the cost of retrofit. Thus, such anticipatory adaptation can substantially reduce the overall lifetime cost of the project, particularly if currently foreseeable but not certain impacts like sea level rise or extreme floods were to occur. Likewise, it is well-known that building more efficient houses and cars at the outset is much less costly than trying to retrofit them once they have been built.

Another way in which anticipatory adaptation can take place is to make investments in agricultural research. For example, we know that if there is an increase in the probability of droughts and floods, as it is appearing to be increasingly likely, then agronomic research in which crop varieties or farming techniques that are more resilient to large climatic variations would provide a measure of security against those variations as they unfold. And even if they did not unfold, such resilience would help us deal with the ordinary climate variability, which already causes substantial year-to-year variations in agricultural productivity, even in technologically advanced countries like the United States.

Finally, a form of adaptive strategy is simply the development of alternative energy technologies. That is, should the world decide in the next decade or so that it really does wish to avert the potential for "dangerous interference" in the climate system as the FCCC words it, it would be much more expensive to replace these conventional energy systems if there were no previous enhanced research and development efforts to experiment with nonconventional alternatives in advance of their urgent need. Therefore, investment in alternative energy systems to conventional fossil energy provides a measure of anticipatory adaptation that would make future adjustments much less expensive than if we simply pretend that business is usual is the safest and best path, and luck turns against us as new studies prove climate change to be in the mid-to-upper range of currently projected damages.

Question 2. You stated in your testimony that it was difficult for plants and animals to adapt to a temperature increase of 5°C over the 10,000 year period following the last Ice Age and that many species would likely go extinct with a kind of rapid temperature increase projected for the next century. Assuming, for the purpose of this question, that the Earth experiences a temperature increase of greater than 1.5°C over the coming 100 years, what is the likelihood that species will successfully adapt? If, in your opinion, this represents a threat to preserving biological diversity, to your knowledge has there ever been a period in the paleoclimate record where climate change has resulted in significant loss of species?

Response. Let me answer the last part of Senator Baucus's question first. There are a number of periods in paleoclimatic records where rapid climate change resulted in dramatic loss of species. The obvious example is the famous "Cretaceous/Tertiary boundary", in which temperature changes on the order of 10 degrees *per year* likely accompanied an asteroid collision with the earth. Half the existing species in the world disappeared, including dinosaurs. Fortunately, no one envisions such a catastrophic rate of change! However, climate change is not the only factor by which humans disturb nature. It has long been argued by ecologists that the fragmentation of habitats, forcing wild species into smaller and smaller refuges with fewer resources and higher competition than they would normally experience, is a threat to preserving biodiversity. Indeed this "conventional ecological wisdom" has led such luminaries as E.O. Wilson at Harvard to predict a mini-extinction crisis, which, viewed from the perspective of hundreds of years, might look in some future geological record almost as if an asteroid had hit the earth today.

But, if we combine the fragmentation of habitats, the introduction of thousands of chemicals for which most creatures have no evolutionary experience and which are often toxic, the transport across natural biogeographic barriers of so-called "exotic species," and combine these stresses on natural systems with climate change at rates of degrees per century (as opposed to degrees per thousand years that are more typical in the past 10,000 years), then I am confident that it would be very difficult for many species to survive such a combination of human pressures without an unnaturally large number of extinctions. Whether such extinctions would be counted "only" in the several percent range or the tens of percent range, as many ecologists predict, is of course impossible to know now. But, it would seem to me almost certain that a dramatic increase of unnatural extinction rates would occur from this combination of fragmented habitats and rapidly changing climate. Even if we were to substantially expand our network of reserves and to interconnect them to allow migration corridors, actions that would certainly reduce somewhat our damages to nature, I still doubt we could prevent substantial loss of biodiversity. However, careful conservation practice, maintaining conservation areas, ecosystem restoration, maintenance of adequate wetlands, and cost-effective priorities for conservation investments, probably could go a long ways toward offsetting a significant fraction of the damages that we would likely otherwise inflict on nature.

Finally, without requiring an asteroid collision and its unbelievably rapid, large climate change, we do know that extinctions occurred at the end of the last ice-age, in which the "charismatic metafauna" such as mammoths and saber-toothed tigers disappeared. This is a time in which there were many "no analog" habitats, brought about by nature's typical sustained rates of climate change: on the order of degrees per millennium. I am virtually certain that degrees per century of climate change sustained over a century or more and combined with fragmented habitats would, as stated earlier, substantially increase the extinction rates of species all around the world.

Question 3. Dr. Lindzen referred in his testimony to a natural mechanism that would be employed by the Earth to counteract the predicted climatic changes due to the effect of increased water vapor in the atmosphere. Are you aware of any historic reference or specific research that would support a theory of the existence of such a mechanism?

Response. Dr. Lindzen referred in his testimony to natural mechanisms that could counteract the rate of climate change, as he has done many times in the past and in different contexts. A number of years ago, he asserted, without proof, that increasing surface temperatures would decrease the amount of moisture in the upper troposphere (between about 5 and 10 miles up). However, a number of observational studies show that when the North Pacific region warmed, the moisture content of the upper troposphere actually increased, as the computer models suggest, not as Dr. Lindzen speculated. He later "recanted" his position (at least temporarily) when pressed by then Senator Gore at a Senate hearing.

Dr. Lindzen frequently points to physical processes that are known to occur on small-scales, and asserts that since they are not explicitly treated in computer models, that the models necessarily are inaccurate, and, furthermore, he implies this inaccuracy is only in one direction—an overestimate of climate sensitivity. He has never demonstrated that the neglect of such small-scale processes makes any difference at the scale at which these models operate (hundreds of kilometers across). A scientist must demonstrate *how* small-scale processes matter to events at large scales, and then demonstrate that the poor treatment of such processes will change the climate sensitivity in a given direction. Neither Dr. Lindzen nor anyone else has demonstrated that poor treatment of each of these small scale processes necessarily matters at large scales, let alone in what direction a better representation of them

would alter our predictions. Quite simply, these are theoretical speculations and Dr. Lindzen has asked the world to wait until these complex, technical issues are thoroughly resolved before paying attention to the current state-of-the-art—imperfect as it is—in modeling.

To me, what is essential is the validation of existing tools, not their theoretical completeness (see my written testimony on this). Validation studies produce mixed results, of course, but, generally support the basic predictions of the magnitude of change in the climate models, not a tenth of that magnitude that Dr. Lindzen repeatedly asserts is the most likely outcome.

Furthermore, in his written testimony, Dr. Lindzen said that satellites suggested that the computer models underestimated the amount of water vapor in the upper troposphere sufficiently to cause an error of about 20 watts per square meter in the models' natural greenhouse effect calculations. He compared this 20 to the 4 watts per square meter that a doubling of CO_2 would add in terms of trapped infrared heat and implied we somehow can't detect a consequence from about 4 watts per square meter heat trapping when the absolute error in the models is 20 watts? Dr. Lindzen knows, as we have personally debated this issue before, that this is a misleading comparison. Since any error a model may make in the *absolute* amount of energy that it calculates the natural atmosphere traps is also an error that would take place both in the model's control experiment, and in the experiment in which carbon dioxide were increased. In other words, the error would subtract out from these two experiments, leaving no difference at all unless the processes involved are what we call "nonlinear." Indeed, processes are nonlinear in the climate system, but Dr. Lindzen has never shown that any such nonlinearity would reduce the sensitivity of the climate, as it could increase in sensitivity. The scientific community is well aware of these issues, tries to test them as best as possible, and would never confuse *relative* and *absolute* accuracy. By way of analogy, if I normally weighed 180 pounds, got on my scale and it said 190 pounds, I would be angry at the absolute error in my scale, but would get used to it over time. If a month later, after overindulging in too many desserts, I step on the scale and it read 193, I would be remiss to say that because the 3-pound relative increase is less than the absolute error of 10 pounds in the scale, that therefore the 3-pound increase can't be taken seriously. Obviously, had the scale been properly calibrated to 180, it still would have come out at 183, or perhaps 182 or 184 if the scale were slightly "nonlinear." But by and large, the absolute error would make very little difference in the sensitivity of the scale to measuring change. That is the fallacy in Dr. Lindzen's comparison of the 4 watts per square meter CO_2 doubling heating effect with the 20 watt per square meter absolute error in the baseline calibration of the models he claims exists. I apologize for the technical complexity of this answer, but I feel that it is important to focus on that statement so as to emphasize the very little credibility that it deserves.

Question 4. Dr. Lindzen stated in his testimony that the one specific feature that led to the IPCC conclusion of a discernible human influence on global climate, . . . "disappears when additional data is considered." Are you aware of specific "additional data" that was not considered or erroneously applied that would cause the IPCC to reach a different conclusion? Are you aware of a specific research result or model that supports Dr. Lindzen's claim? If so, did you know whether the IPCC considered it? Are you aware of other factors that the IPCC relied upon to conclude that human activities were impacting global climate.

Response. This is a very complicated issue, which I will try to answer as briefly as possible, but still will take several paragraphs. In short, IPCC in 1995 had not considered the additional data that Dr. Lindzen refers to, because it was not available to the analysis team at the time the analysis was performed. However, the very same authors who performed the analysis have not only considered such data recently, but they have incorporated it into subsequent analyses and their conclusions remain the same, in fact, they are strengthened. I strongly urge that you contact Dr. Ben Santer from the Lawrence Livermore National Laboratory, who will be able to explain this further. There is a debate in *Nature* magazine (12 December 1996 issue) in which you can find further technical details. In short, the argument is simply this. The first analysis that the IPCC debated was based on a calculation at Lawrence Livermore National Lab, in which carbon dioxide increases and aerosol increases from pre-industrial values to present were used and compared to carbon dioxide increases alone. The agreement between the models and observations was much better when the aerosols were included, which is what one might expect since aerosols also are part of the human impact on climate in the real world. However, the real world did not experience a fixed increase in either carbon dioxide or

aerosols, but rather these "radiative forcings" changed with time—what we call transient experiments (see my written testimony).

The first studies which Dr. Santer and his colleagues performed involved equilibrium experiments. It turns out, and government officials should be proud of this, that environmental controls on air pollution that generates sulphate particles (because of their potential hazards to human health) caused a reduction in the emissions of such sulphates from the mid-seventies through the 1990's in North America and Europe. Therefore, a better way to perform the climate experiment would not be to put in a fixed amount of sulphate, as was done in the initial Santer et al. experiments, but to allow Northern Hemispheric sulphate to increase rapidly from post-World War II to the mid–1970's, then allow it to reduce due to air pollution controls, and then start to increase again in the 1990's because of Chinese emissions. Since the IPCC 1995 report, additional transient experiments with such time-varying sulphate forcing patterns have been performed, and that Dr. Santer and colleagues (as reported briefly in the previously cited *Nature* debate) have shown that when this more correct sulphate forcing is applied to climate models, it gives a particular shape of response, which is similar to the shape that is observed when the "additional data," to which Dr. Lindzen refers, is included. So the reason Dr. Lindzen asserts that the additional data invalidates the original conclusion is because Dr. Lindzen is applying the additional data to the equilibrium experiment—and the agreement becomes worse. But when this new data is applied to the transient experiment, the agreement between model and observations becomes even better. Since the transient experiment is the better representation of reality, the "additional data," in my opinion, would improve one's confidence that a "discernible human influence" on climate has occurred.

Finally, let me say that it is absolutely incorrect to assert (as Dr. Lindzen does in his written testimony) that the IPCC lead authors, and I was one of them, used the "discernible" phrase because of this one additional "specific feature" that Dr. Santer and 11 other colleagues presented. Indeed, there were many lines of evidence, of which this "specific feature" was one, and if any one of them collapsed, it would not eliminate the preponderance associated with the others. These other factors include (1) a well validated theory of heat trapping, (2) a well established century-long 1/2°C warming trend of the earth, (3) geographic patterns of climate change with CO_2 and aerosols which begin to match observed patterns, (4) mountain glacier retreats, (5) rising sea level, (6) ability of the models to reproduce the different seasonal cycles of surface temperature in the Northern and Southern Hemispheres, and (7) the capacities of models to reproduce cooling of the lower atmosphere following volcanic eruptions in roughly the same amount as was observed. The "discernible" statement was clearly not based on one line of evidence.

Question 5. Do you believe there is sufficient evidence of a problem with human-induced climate change for us to keep pursuing some kind of policy to limit CO_2 emissions? If not, should we stop funding research that would tend to prove or disprove the theories that human activities are impacting global climate? If there is sufficient evidence, what more, if anything, should we be doing?

Response. With due respect to Senator Baucus, asking the question about "sufficient evidence" to "keep pursuing some kind of policy to limit CO_2 emissions" is clearly asking me for a value judgment. However, since I have been asked for my values many times, and they are well documented on the record through many congressional testimoneys and four published popular books (most recent being *Laboratory Earth: A Planetary Gamble We Can't Afford to Lose,* Basic Books, 1997), I will not hesitate to restate that opinion here.

Indeed, as I said in my oral testimony on July 10, I have believed that there has been "sufficient evidence" for the past 20 years to limit CO_2 emissions, not because I was certain of the precise nature, timing, and distribution of consequent damages, but simply because I am a risk-averse person who doesn't believe in taking irreversible chances—especially with the life-support systems of the planet, particularly when alternative energy systems already exist, and modest research development programs, along with incentive programs that could be spurred through more realistic energy pricing, could very well reduce substantially our impacts on the atmosphere. This, to me, is fundamental planetary insurance against the first decimal place odds chance of substantial damages, particularly in areas such as biodiversity loss.

With regard to whether we should stop funding research that would "prove or disprove the theories," I have two reasons to disagree. The first is plain self-interest: as a scientific researcher interested in understanding how nature works, it would be hard for me not to advocate pursuing further knowledge for its own sake. With that self-interest aside, the second reason may prove more compelling to some in

the Congress. That is, we need to understand how the system works, and how it changes, and how we might or might not be damaging it not only to help us decide how much carbon emissions to mitigate—the adaptive management issue referred to in question 1—but simply to help us learn how to adapt more effectively to whatever change might occur. Suppose we chose as a matter of policy to take the risk that climate change will not be serious and allow the earth to "perform the experiment" for us. Let us also suppose, that some damages unfold (both not unlikely assumptions, I'm afraid). In that case, the amount of damages that would eventually occur would depend upon on our capacity to forecast accurately what further changes would take place. For example, it is much easier for farmers to adapt to changes that are known in advance, for water supply planners or health officials to make contingency planning to deal with known changes than random or unforecasted changes. Likewise, wildlife managers could deal with artificial wetlands or migration corridors or other more cost-effective planning activities if they knew precisely what changes would unfold than if changes simply occurred unanticipated. Therefore, even if we choose to do nothing now to abate carbon—believing that any amount of uncertainty is sufficient grounds to do nothing (which I think is inconsistent with most personal and business investment practices)—we still would need the kinds of scientific information that the research community can provide in order to make adaptations more efficient and ultimate damages to incur lower costs.

Since I argue that more research is important, you ask "what more" should we be doing. First, I think we need to integrate work in physical, biological, and social areas. I think that most areas of physical climate research are already in relatively good shape, and the most important thing in this area to watch is some continuity in funding, so that research groups aren't always spending so much time fighting for new grants. The amount of effort scientists put into grant writing these days because of unreliable funding often starts to equal the amount of effort they put into their own research. So, continuity and stability would strike me as more important than any particular increase in overall effort in physical science or climatology. With regard to biological research, I think there needs to be more coordination so that interdisciplinary activities across biological and physical research groups could continue to expand. The rewards systems in science don't often provide incentives to interdisciplinary researchers, and I think that universities and government labs could use some encouragement from Congress and funding agencies to support such applied, but fundamentally interesting, interdisciplinary work. Finally, I think we have put too little relative effort into asking the question, "So what if the climate changes?" I think more coordinated efforts to perform "integrated assessment" of the human activities which threaten to create climate change, which affect how we could adapt should such changes occur, and which evaluates the distribution of damages need a boost. Even more than for physical scientists, funding is spotty and unreliable, and impact assessment researchers spend a large fraction of their time in defensive posture pursuing grants rather than basic work. Furthermore, academic institutions are less likely to employ such people as they are not always valued as highly as "basic researchers."

Finally, I think the economics community has taken major strides toward studying the potential costs of carbon abatement as well as the benefits of such abatement. Although all that work has accelerated, it is still at a relatively early stage of development, and not only does more of such work need to be done, but it needs to be better coordinated with those who study climate damages and the community that produces climate systems research. In a nutshell, it would be nice if we had, as the now defunct National Climate Program Office was supposed to do when it was first mandated by Congress in 1978, some central tracking office to make sure that wasted overlaps do not occur, and that serious research gaps do not also occur. Some office needs to help provide some continuity of funding for observations and modeling so that the research community can spend most of its time working, rather than frantically pursuing the next grant dollar for survival.

Question 6. In your professional opinion, what is the probability that there will be a doubling of CO_2 concentrations since pre-industrial times by the year 2100? A tripling? What are the impacts of a doubling? What are the impacts of a tripling?

Response. The probability that there will be a doubling of CO_2 concentrations since pre-industrial times by the year 2100 is very high. If we include the combined effects of carbon dioxide, methane, and fluorocarbons, I think the probability is very close to one. It will be exceedingly difficult to turn off the population growth, economic growth and fossil fuel growth engines of this planet before the equivalent carbon dioxide concentration (i.e., CO_2 plus methane, fluorocarbons, etc.) reaches the heat trapping equivalent of 550 parts per million CO_2—probably before the middle

of the next century. However, if we begin to invest in alternative technologies, and turn lose the impressive capacity of our industries to invent and deploy more efficient systems, I think there is no justification to go beyond that equivalent doubling of CO_2. Indeed, we could hold heat trapping from CO_2 well below a doubling if we were to aggressively pursue all "no-regrets" energy-efficiency options now, as well as perform the needed research to enhance efficiency and lower the costs of less carbon-intense alternative energy systems. I also believe we would have to engage in "planetary bargains" with countries like China and India, especially if the differential cost of their building more efficient, less polluting power plants were borne by richer countries. In this way, the Chinese would not lock in inefficient, high CO_2-producing coal burning power plants now whose operating lifetime could be near five decades. Since I do not believe it is likely that such an international effort will get very far in the near future, I give a fairly high probability to the equivalent doubling of CO_2. I believe also that the equivalent tripling of CO_2 by 2100 is quite likely if the world pays no attention to the alternative pathways for energy development, and the continuation of international non-cooperation on energy and protection of global commons is maintained. I am hopeful that will not be the case, although I am fearful this may only happen if environmental disasters motivate attention—something I recall Senator Baucus said in his oral remarks during the hearing and that I unhappily, but professionally, agree with.

With regard to the impacts of doubling of CO_2, I think that there is a 5 or 10 percent chance that that doubling could be relatively modest in its effect on climate (on the order of 1°C or less temperature rise), and I think that there is probably a 10 percent chance that it could be potentially catastrophic (something like 4–6°C or more). I think it is most likely that 2–3°C will occur as a result of that doubling, but that alone occurring over a century, would, as I said in answer to question 2, likely cause serious damages to nature in the form of biodiversity loss and dramatically altered habitats, as well as increases in the frequency of hydrological extremes, such as droughts, floods, and sea level rises, and other disruptions to our normal activities that depend on climate. I feel the impacts of a tripling would be substantially worse than those of the doubling, for a tripling could well cause climate changes of 5°C or more, and in such instances major surprises, such as a flip-flop in North Atlantic ocean currents, large releases of stored carbon compounds in soils and bogs, and other currently "imaginable surprises" would be much more likely to occur. I think that virtually any currently imaginable definition of "dangerous climate change" would insist on holding the future amount of carbon dioxide for doubling or less, and indeed a cogent case could be made for holding the increase to no more than 450 parts per million, although I recognize that to do that would require significant policy actions right away.

RESPONSES BY DR. STEPHEN H. SCHNEIDER TO ADDITIONAL QUESTIONS FROM SENATOR BOXER

Question 1. We hear about natural climatic cycles. For example, we know from geologic evidence that the earth has naturally gone through cooling and warming cycles, usually on a scale of 10's of thousands of years.

Question 1a. Is it possible to identify cycles of a shorter scale?

Response. Yes, there are shorter scale cycles, but the very large ones occur on tens of thousands of years (like ice ages and interglacial cycles, whose peak-to-peak temperature differences are in the order of 5°C—9°F). Smaller scale cycles usually involve changes that are 1°C or less. Remember, we are talking about the "best guess" for human-induced climate changes in the next century of several degrees, larger than the short scale effects. For example, during the early part of the current millennium, exploration of Greenland in a so-called "medieval climatic optimum" took place, in which temperatures in the North Atlantic region were perhaps one to two degrees warmer than now. However, on a globally averaged basis, it is unlikely surface temperatures were even 1°C warmer. A few centuries ago, Europe and parts of North America were particularly affected by a so-called "little Ice-Age," between about 1500 and 1800. Again, temperature decreases in northern latitudes were on the order of 1°C colder relative to today, and globally probably 1/2°C or less. Thus, the magnitude of unnatural change that is typically projected as likely in the next century swamps these short-term cycles, which is why scientists frequently discuss the tens of thousands of years scale cycles for points of comparison, noting how rapid the typically projected human-induced climate change is likely to be relative to the large changes between ice ages interglacials.

Question 1b. Would we be able to detect variations attributable to human activities in this natural cycle?

Response. This is an excellent and very difficult question, and one of the most controversial ones in climate science. One thing that needs to be stated first is that the words "detect" and "attribute" are quite separate in the minds of scientists. For example, to detect a climate change all we need to show is that it is relatively unusual given the natural cycles that occur. A 1/2°C warming trend of the twentieth century is relatively unusual. I have estimated from looking at paleoclimatic indicators that it is perhaps a 10 percent chance that the twentieth century trend was entirely due to natural causes. Furthermore, recent evidence from Dr. Tom Karl at NOAA in Asheville, shows that since 1910 the U.S. has experienced a 10 percent increase in precipitation, and that more than half of that increase in precipitation occurred in the upper decile of precipitation intensity—i.e. most of the increase occurred in "gully washers" rather than gentle rains. The statistical significance of this finding is very high—that is, there is little doubt that this is the detection of a real climate change. The attribution problem is whether this is just "double snake eyes" from a perverse nature, or have we begun to "load the climate dice"? The latter is much more difficult to establish, and requires statistical testing, mathematical models, multiple kinds of evidence and is precisely the kinds of activities that the scientific community has been vigorously pursuing over the past 10 years. The most recent IPCC report, in which roughly 100 lead authors spent days debating this one point, led to the cautious, but nonetheless strong assertion, that "the balance of evidence suggests that there is a discernible human impact on climate." I think this cautious statement goes about as far as the bulk of the community would allow, namely, a strong confidence that we are at least partly in the act, but that given the large degree of natural variability, until another decade or two elapses, in which case predicted effects should become even larger and therefore the probability of perverse nature even smaller, there still would be debate over this topic.

Question 2. We know that CO_2 has the potential for affecting the climatic balance of our atmosphere. Would it not make sense to limit the amount of CO_2 we put into the atmosphere until we more fully understand the effects CO_2 has on our climate?

Response. This question, of course, calls for a value judgment about whether one fears more performing unplanned experiments on what I like to call "Laboratory Earth" or whether one fears more what the economic or social consequences would be from those actions which tend to reduce the pollutants. This is a balance of values question, and in my value system, which is risk averse, I don't like to take potentially irreversible chances with the life support systems of the earth. Nor do I like to risk committing future generations to have to adapt to potentially large changes that they had no participation in creating. In my value system, when we pursue activities that benefit us with the potential for irreversibility and the potential for causing harm to persons other than ourselves, these conditions lead me to limiting the amount of CO_2, simply as planetary insurance that ethical people would undertake until they were more sure of the relative harm or benefits that our unplanned experiment could create.

Question 3. In your testimony, you mentioned the incentive that a carbon tax would have upon emerging "clean" industries. What kind of industries do you think would emerge?

Response. I feel that a carbon tax would have several positive benefits, as explained in the Appendix to my written testimony (the Commentary now accepted by Nature magazine by Professor Larry Goulder and myself). First of all, a fee for dumping carbon in the atmosphere sends the right signal to a market-based economy, that the atmosphere is not a valueless commodity, and cannot be used as a "free sewer." In other words, how can a market system be efficient, if not all costs are part of the price. The price of energy is not simply extraction, transport, storage and profit, but also damages that each system differentially inflicts on people's lungs, sea level, nature, and so forth. Those systems which damage more should be charged more, otherwise a market system cannot work—these unpriced side effects are what economists call externalities. Internalizing these externalities, in my opinion, is most simply accomplished by a carbon tax, which, as I said in answer to Senator Baucus's question, also is a highly flexible policy instrument that can be cranked up or down as new knowledge tells us that the perceived problem is more or less serious than currently believed. Furthermore, a carbon tax not only causes billions of individuals to be more conscious of the energy components of the activity—that is, the energy component that produces carbon dioxide—but serves as a major stimulus to alternative energy systems and to energy efficiency. It is already a fact that when the OPEC countries dramatically and precipitously increased the price of energy in the early seventies, this caused significant economic harm because of the precipitousness of the price shock. However, it is also a fact that after a temporary adjustment, structured changes to the economy and the inventive genius of

our technologists caused a significant drop in the amount of energy it took to produce a unit of GDP in the developed countries of the world. In other words, we invented more efficient technologies and alternative ways to run our economy (e.g., information in computers rather than logs on tracks) on less energy. These effects have indelibly improved our economy and part of the economic boom we now enjoy is because of the structured changes and extra efficiency that was induced by that temporary oil price rise. Only after the prices decreased in the 1980's did we lose the great rate of progress that we were making in improving energy intensity. In other words, despite the political resistance to higher prices of energy, such price incentives have been demonstrated to stimulate improved technology which actually helps the economy over the long term. The key lesson is not to have any price rises which are both unexpected and precipitous.

In addition to improving energy efficiency, alternative energy systems would be encouraged by raising prices of conventional energy. Investors in solar, wind, fuel cells, more efficient natural gas, and perhaps even safer and cheaper nuclear energy would all feel more investment opportunity if they knew that there were to be a sustained increase in conventional energy prices that would give them a larger potential market share. The more investors are willing to pump into research and development activities in these alternative energy systems, the more rapid progress would be made which will bring down the ultimate price of those alternative energy systems. This is not simply a way of reducing carbon more cheaply, but may very well in the long term help our economy materially in the following way. We know that oil is becoming increasingly scarce, and that after the next decade or so world oil production will no longer increase each year, despite further exploration activities, but will begin to decline, as has been long predicted. Oil prices will then increase. The question is, What will replace them? Isn't it better to replace them with cleaner alternative energy systems than coal or oil shales, and how can these cleaner systems compete with the dirty systems, unless the clean ones have had adequate research and development opportunities. Therefore, carbon taxes, or R&D subsidies, or other mechanisms that provide incentives for research seem to me essential regardless of the climate problem, as anticipation for dealing with the inevitable increase in fossil energy prices over the long run, which will require the development and deployment of substitutes, which, if we have foresight and pursue more vigorously now, will not only reduce greenhouse gases slightly today, but also will give us the opportunity for dramatic greenhouse gas reductions (relative to "business as usual") should new science prove that to be necessary. Development of alternative economic and energy systems provides a measure of protection against the inevitable increase in energy prices that will accompany the scarcity in fossil fuels as the oil era winds itself down in the first few decades of the 21st century.

Question 4. What are the three most important things that need to be done to address global climate change?

Response. As I have said in my oral and written testimoneys, I believe the first most important thing to do is to send a message that the atmosphere is not a "free sewer." That is, some charge for the use of the global commons needs to be part of the price of doing business, so that the true costs to both the economy and ecology can be better incorporated into the price of commodities. The second thing is to improve the resilience of our systems to whatever changes take place—natural or human induced. In other words, developing more resilient agriculture, water supplies, biological reserves, and so forth, is an insurance policy not only against potential human-induced climate changes, but also against natural variability that nature often thrusts on us with or without climate change. Finally, I think one of the important things to do to deal with climate change is one of the important things to do for living in a secure 21st century-world: putting the question of sustainable development at the top of the world's agenda, not near the bottom. One poignant metaphor reminds us that all in the ship are at risk when one end is sinking. Clearly, developing countries have a right to be concerned that worries about global commons like the atmosphere might just be another excuse of the developed countries to restrain the competition that these developing countries will provide as they industrialize. My view is that we should be partners in that development, helping to transfer efficient and less polluting technologies, even via concessionary terms, for which we get back in exchange better relations, future customers, and less of a legacy of pollution and degradation for us and our posterity. I personally believe there is much too much emphasis around the world on international competition and national competitiveness, and insufficient attention to cooperative win/win solutions in which countries like China can use high technology to jump over the Victorian industrial revolution in which the now rich countries used inefficient, polluting technologies to build their wealth. I recognize how large these questions are and that

planetary foresight is called for, and hope that the public education needed to achieve political acceptability of such planetary bargaining strategies becomes a reality, before large climate change and loss of biodiversity, coastal flooding, and other kinds of tragedies finally catalyze public consciousness after much preventable damage has occurred.

PREPARED STATEMENT OF DALE W. JORGENSON, PROFESSOR OF ECONOMICS, HARVARD UNIVERSITY

Mr. Chairman, distinguished members of the Committee on Environment and Public Works: I am very grateful for the opportunity to participate in these Hearings on the scientific understanding of global climate change. My testimony will focus on the economics of climate change. As a point of departure I will use the "Economists' Statement on Climate Change" included in my written testimony. I was one of five co-authors of this statement, which was circulated in January of this year and has now been endorsed by 2,600 economists, including eight Nobel prize winners.

The first paragraph concludes that global change involves significant environmental risks and preventive steps are justified. The second paragraph summarizes economic studies showing that there are policies for reducing greenhouse gas emissions with benefits that outweigh the costs. The third paragraph describes these policies in more detail and emphasizes the importance of relying on market-based mechanisms.

The economics of climate change can usefully be divided into three parts. The first is determination of the overall objective of climate policy. The economists' approach to this problem is to choose a policy that produces the greatest margin of benefits over costs. Using economic jargon, I will refer to this as the "optimal" policy. Such a policy would stipulate a time path for future emissions of greenhouse gases that could be embodied in an international agreement.

After an overall objective is chosen, the second step is to devise a means of implementing this goal. Emissions of greenhouse gases would have to be allocated among the signatories of an agreement. In addition, emissions by countries that are not signatories would have to be taken into account, since the global climate is affected by total emissions. Third, given an allocation of greenhouse gas emissions among countries, each country would have to implement its emissions goal by devising policies that would hold emissions within the prescribed quota. Furthermore, the international community would have to monitor emissions for all countries.

Let me begin with an evaluation of our existing climate policy, the Climate Change Action Plan (CCAP) of 1993. This Plan consisted of voluntary actions projected to reduce emissions to 1990 levels by the year 2000. The goal was stipulated in the United Nations Framework Convention on Climate Change ratified by the United States in October 1993.

The impact of CCAP is summarized in the final chart, which compares a projection of U.S. emissions of greenhouse gases under the original CCAP "baseline," projecting emissions without the Plan. The CCAP actions were projected to reduce emissions to 1990 levels by the year 2000. The third line on the chart gives actual U.S. emissions through 1996. These are above the CCAP baseline and far above emissions levels required for stabilization. Clearly, we need to consider alternatives to our existing climate policy.

The starting point for a discussion of climate policy is the damages associated with a change in the climate. This is based on combining a physical description of the climate with an economic description of the world economy. This type of analysis is called "integrated assessment" and an assessment of this type has been carried out by William Nordhaus of Yale University in his 1994 book. The loss associated with climate change is 1.34 percent of world product in 2050.

How large are the damages associated with climate change? They are equivalent to the loss of about 1 year of world economic growth. Obviously, this is sizable, but not overwhelming. In the view of the signatories of the Economists' Statement on Climate change, this is sufficient to justify preventive steps to reduce greenhouse gas emissions.

Next, suppose we choose reductions in emissions that will produce the maximum difference between costs and benefits. How large are the benefits of this policy? Nordhaus has calculated the benefits for the world as a whole to be equivalent to $271 billion dollars. This is only 0.04 percent of future consumption! While damages associated with climate change are substantial, steps to mitigate these damages will produce only very modest effects.

Let me emphasize at this point that the policy I have described conforms to the Economists' Statement on Climate Change. Preventive steps are justified. Policies like the one I have described would reduce greenhouse gas emissions and could employ market-based mechanisms to do so. A policy appropriate for international implementation would be the system of internationally tradeable permits described in the U.S. Climate Change Proposal of January 17.

For domestic implementation of the optimal climate change policy an appropriate market mechanism would be to impose taxes on greenhouse gas emissions. These taxes would be relatively modest, amounting to an initial tax of $5.29 per ton of carbon and rising to $10.03 per ton by the year 2025. My paper with Peter Wilcoxen, "The Economic Effects of a Carbon Tax," analyzes the effects of a tax on emissions of carbon dioxide, the most important greenhouse gas, in greater detail. Wilcoxen and I calculate the cost of achieving various goals, including the stabilization goal of the United Nations Convention. We also consider different methods for "recycling" the revenues from a carbon tax and find that the economic cost is highly dependent on the use of the revenue. Finally, we consider the use of alternative tax instruments, such as a "Btu" tax on energy and an ad valorem tax on energy.

Our overall conclusions are, first, that a carbon tax is superior to other tax instruments. Second, by using the revenues to reduce the most burdensome taxes, namely taxes on income from capital, economic growth can be stimulated rather than retarded. Of course, reducing the tax burden on capital by substituting other forms of taxation would produce similar effects with no effect on emissions of greenhouse gases.

To sum up: The economics of climate change is well understood. The optimal policy, described in more detail in my written testimony, involves a modest reduction in the growth of greenhouse gas emissions. This should provide the basis for any international agreement that would supersede the United Nations Framework Convention of 1994. However, this involves smaller reductions than our existing climate policy, the U.S. Climate Change Action Plan.

The U.S. Climate Change Proposal from last January contains a useful contribution to international implementation by proposing a system of internationally tradeable permits for emissions. Domestic implementation requires a process for setting country-specific quotas for emissions. This might impose lower or higher reductions in emissions for the U.S., relative to other countries. After the U.S. quota has been determined, the final step would be to impose a tax on emissions like the carbon tax discussed in my paper with Wilcoxen.

SHORT READING LIST

William J. Clinton and Albert Gore, Jr., THE CLIMATE CHANGE ACTION PLAN, Washington, Executive Office of the President, October 1993.

Dale W. Jorgenson and Peter J. Wilcoxen, 'The Economic Effects of a Carbon Tax," in Henry Lee (ed.), SHAPING NATIONAL RESPONSES TO CLIMATE CHANGE, Washington, The Island Press, 1995, pp. 237-260.

William D. Nordhaus, "Analysis of Policies to Slow Global Warming," Chapter 5 in MANAGING THE GLOBAL COMMONS, Cambridge, The MIT Press, 1994, pp. 77-100.

The World Bank, 'International Environmental Concerns," Chapter 8 in DEVELOPMENT AND THE ENVIRONMENT, New York, Oxford University Press, 1992, pp. 153-169.

ECONOMISTS' STATEMENT ON CLIMATE CHANGE

Endorsed by Over 2000 Economists including six Nobel Laureates

I. The review conducted by a distinguished international panel of scientists under the auspices of the Intergovernmental Panel on Climate Change has determined that "the balance of evidence suggests a discernible human influence on global climate." As economists, we believe that global climate change carries with it significant environmental, economic, social, and geopolitical risks, and that preventive steps are justified.

II. Economic studies have found that there are many potential policies to reduce greenhouse-gas emissions for which the total benefits outweigh the total costs. For the United States in particular, sound economic analysis shows that there are policy options that would slow climate change without harming American living standards, and these measures may in fact improve U.S. productivity in the longer run.

III. The most efficient approach to slowing climate change is through market-based policies. In order for the world to achieve its climatic objectives at minimum cost, a cooperative approach among nations is required—such as an international emissions trading agreement. The United States and other nations can most efficiently implement their climate policies through market mechanisms, such as carbon taxes or the auction of emissions permits. The revenues generated from such policies can effectively be used to reduce the deficit or to lower existing taxes.

Table 5.1
Net benefit of alternative policies on discounted consumption

Case	Policy	Discounted Value of Consumption			Impact on Annualized Value of Consumption (billions of $/yr.)
		Base Value (trillions of 1989 U.S.$)	Impact of Program: Difference (billions of $)	Percent Difference	
1	No mitigation	730.90	0	0.00	0
2	Optimum	731.17	271	0.04	11
3	10-year delay	731.14	243	0.03	10
4	Stabilize emissions at 1990 level	723.83	(7,069)	(0.98)	(283)
5	Stabilize emissions at 80 percent of 1990 level	718.38	(12,521)	(1.74)	(501)
6	Geoengineering	736.50	5,601	0.76	224
7	Stabilize climate at maximum of 1.5 degrees C increase	689.92	(40,980)	(5.94)	(1,639)

Notes: The present value of consumption is calculated as the consumption stream from 1990 on discounted to 1990 at the rate of interest on goods and services calculated in the optimal program. Values in parentheses indicate negative values. All values are in 1989 U.S. dollars. Annualized consumption is calculated at rate of interest less rate of growth (equal to .04) times discounted value of consumption.

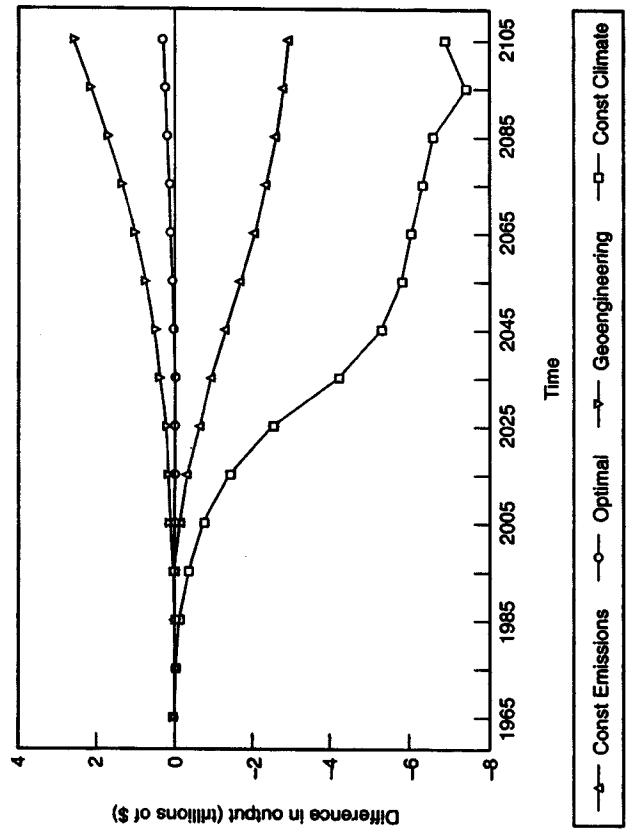


Figure 5.1
Differences in global output
(Difference from no-controls baseline, trillions 1989 U.S. dollars)

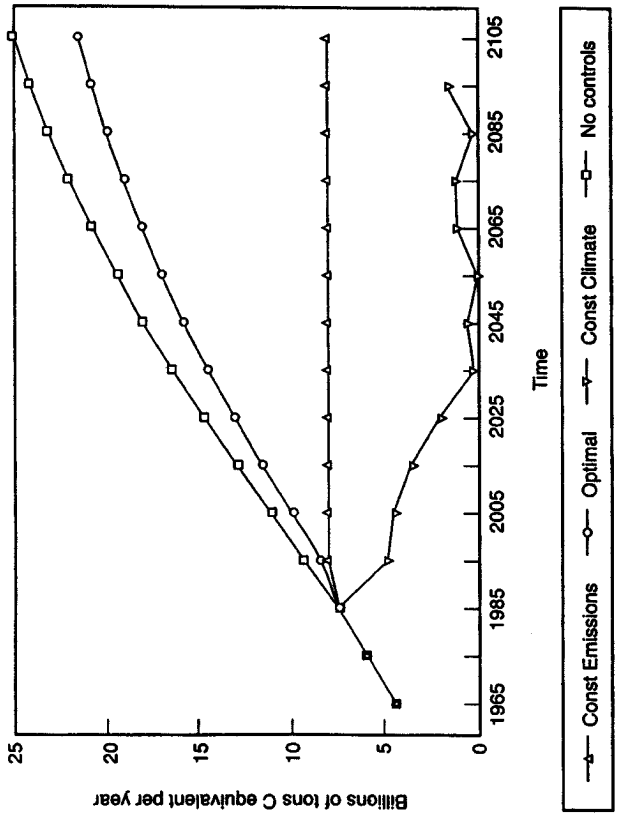


Figure 5.2
Greenhouse-gas emissions (CO_2 and CFCs only)

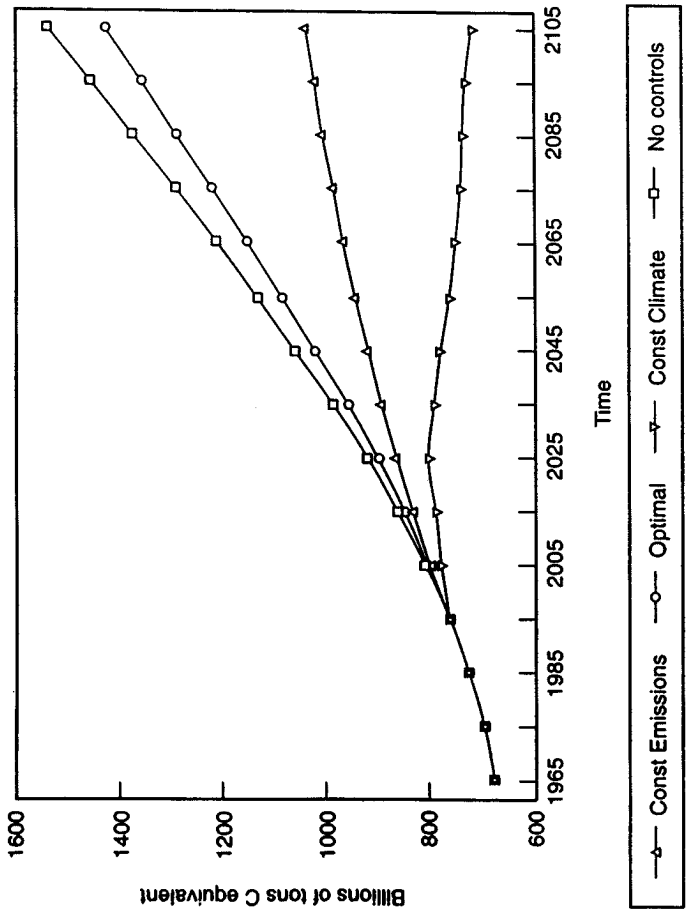


Figure 5.3
Atmospheric GHG concentrations
(CO_2 and CFCs only)

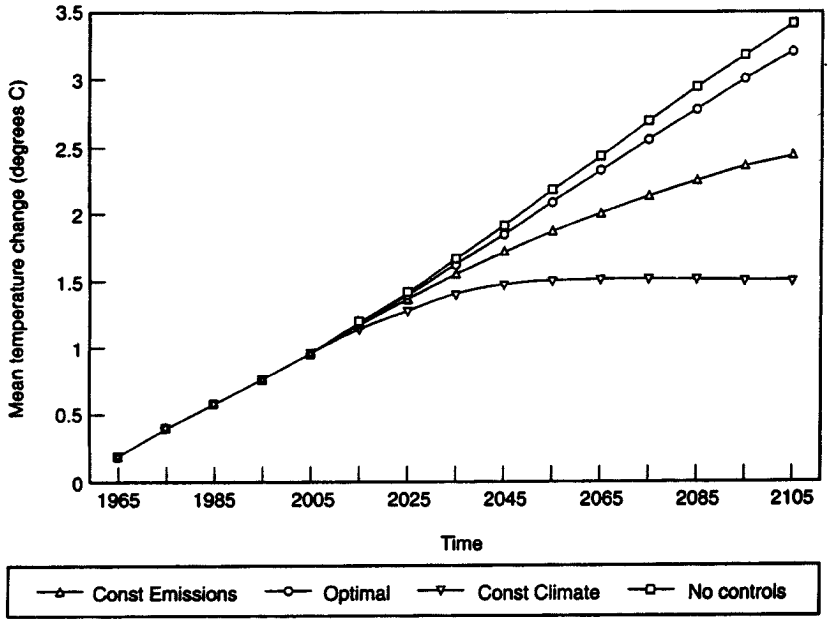


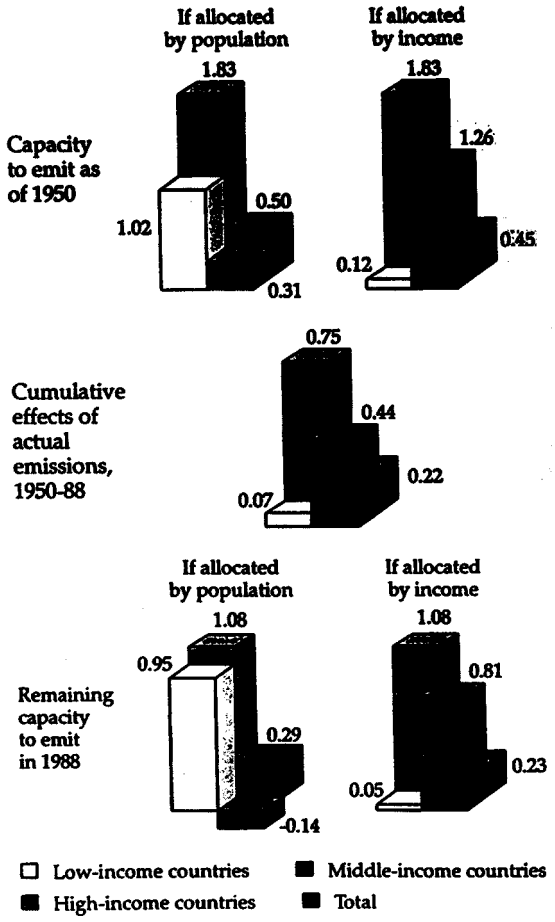
Figure 5.4
Global mean temperature
(Change from 1865)

Table 8.1 Effects of eliminating subsidies on commercial energy in Eastern Europe and the former U.S.S.R. and in developing countries

Effect	*Eastern Europe and former U.S.S.R.*	*Developing countries*
Reduction in emissions, 1995		
Amount (millions of tons of carbon)	446	234
As share of projected regional emissions (percent)	29	11
As share of projected global emissions (percent)	7	4
Cumulative reduction, 1991–2000		
Amount (millions of tons of carbon)	3,796	2,318
As share of projected cumulative regional emissions (percent)	24	11
As share of projected cumulative global emissions (percent)	6	4

Note: The base case is derived from World Bank projections of energy demand. In this scenario, worldwide carbon dioxide emissions increase by about 20 percent between 1990 and 2000.
Sources: World Bank staff estimates using Bates and Moore, background paper; Imran and Barnes 1990; Marland and others 1989; Hughes 1991.

Figure 8.2 Scenarios for allocating capacity to emit carbon dioxide if greenhouse gas warming effect is stabilized at $2xCO_2$
(warming effect of emissions in watts per square meter)



Note: For illustrative purposes, it is assumed that the greenhouse gas warming effect is stabilized at the equivalent of double preindustrial carbon dioxide concentrations ($2xCO_2$). Actual emissions exclude deforestation due to lack of reliable data. 1950 is used as the starting point because the data series on emissions from fossil fuels and cement manufacturing begins in that year.

PREFACE

Last year in Rio de Janeiro, Brazil, world leaders and citizens from more than 200 countries came together to confront the global ecological crisis. The Earth Summit aroused the hopes and dreams of people around the world and set in motion ambitious plans to address the planet's deepest environmental threats. We shared a common mission: to provide a higher quality of life for ourselves and a brighter future for our children.

At the Earth Summit, the United States joined other countries in signing the Framework Convention on Climate Change, an international agreement to address the danger of global climate change. The Convention has been signed by 161 countries and has been ratified by 31 of those countries. The objective of the Convention was stated to:

> *"...achieve ... stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food pro..uction is not threatened, and to enable economic development to proceed in a sustainable manner."*

The international community rallied around the threat of climate change because scientists agree that the risk is real. There is no doubt that human activities are increasing the atmospheric concentrations of greenhouse gases, especially carbon dioxide, methane, and nitrous oxide. All

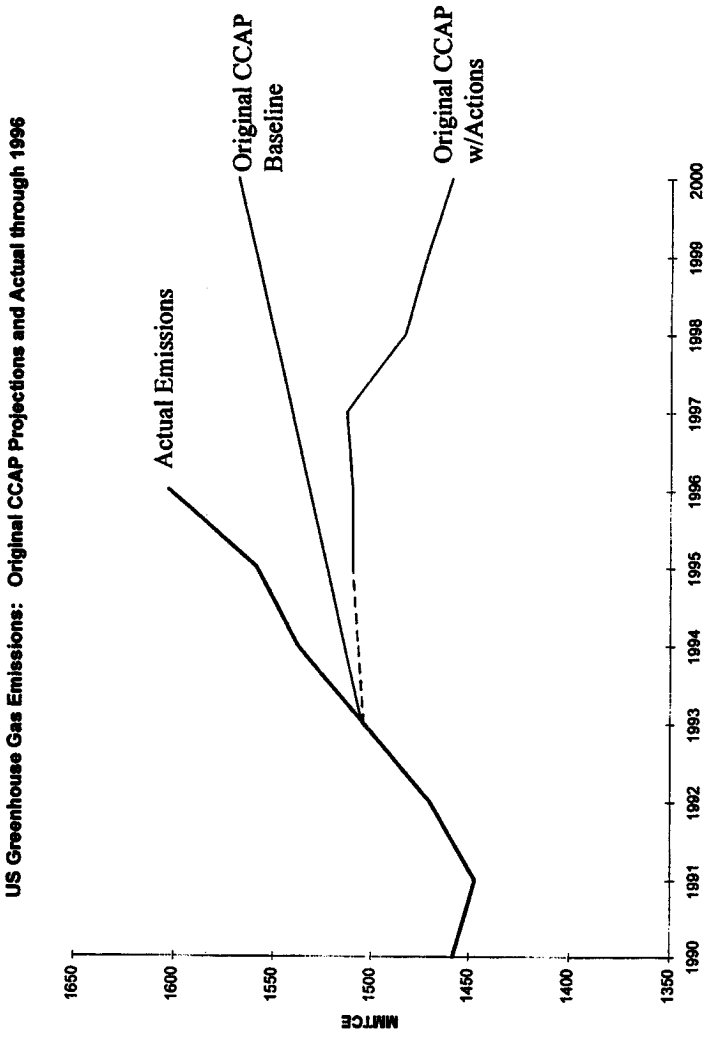
EXECUTIVE SUMMARY

We must take the lead in addressing the challenge of global warming that could make our planet and its climate less hospitable and more hostile to human life. Today, I reaffirm my personal, and announce our nation's commitment to reducing our emissions of greenhouse gases to their 1990 levels by the year 2000. I am instructing my administration to produce a cost-effective plan ... that can continue the trend of reduced emissions. This must be a clarion call, not for more bureaucracy or regulation or unnecessary costs, but instead for American ingenuity and creativity, to produce the best and most energy-efficient technology.

President Clinton
April 21, 1993

President Clinton's Climate Change Action Plan meets the twin challenges of responding to the threat of global warming and strengthening the economy. Returning U.S. greenhouse gas emissions to their 1990 levels by the year 2000 is an ambitious but achievable goal that can be attained while enhancing prospects for economic growth and job creation, and positioning our country to compete and win in the global market.

There is no doubt that human activity is increasing the concentration of greenhouse gases in the atmosphere. The buildup of greenhouse gases threatens to change the global climate system, raise sea levels and inundate coastal areas, inflict irreversible damage to ecosystems, and


US Greenhouse Gas Emissions: Original CCAP Projections and Actual through 1996
Actual Emissions
Original CCAP Baseline
Original CCAP w/Actions
MMTCE
1650
1600
1550
1500
1450
1400
1350
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000

The Economic Effects of a Carbon Tax

BY DALE W. JORGENSON AND PETER J. WILCOXEN

Reprinted from

Shaping National Responses to Climate Change

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Henry Lee

1995

pp 237-260

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8 The Economic Effects of a Carbon Tax

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A carbon tax, such as the one proposed by Bruce Stram in the previous chapter, would have effects throughout the economy. It would raise the price of energy, increase the cost of products produced by energy-intensive processes, reduce employment in energy sectors, increase employment elsewhere, generate tax revenue, and, finally, reduce carbon dioxide emissions.

In this chapter, we use a detailed model of the U.S. economy to calculate the magnitude of these and other effects. Our findings are roughly as follows. A carbon tax would raise fuel prices, particularly for coal. Coal demand would fall substantially, leading to a large drop in coal production. Oil and gas output would also decline, but by a much smaller percentage. Higher coal prices, in turn, would raise the cost of electricity. Consumers and firms would demand less electricity, which would slow productivity growth and capital formation. This, in turn, would tend to reduce GNP.

What actually happens to GNP, however, depends very strongly on how the revenue from the tax is used. A carbon tax large enough to have much effect on emissions would annually raise tens to hundreds of billions of dollars. If this revenue were used to reduce distortionary taxes elsewhere in the economy, the impact of the tax on GNP would be much smaller. In fact, we show that GNP would actually increase if the revenue were used to reduce taxes on capital.

The next section presents our model and uses it to show how a carbon

tax large enough to stabilize carbon dioxide emissions at 1990 levels would affect the United States. We then consider a series of possible refinements on the basic tax: the further reduction of emissions, the different uses of the tax revenue, the alternative use of Btu or ad valorem taxes, and the distributional effect of the tax, and, finally, we explore whether a tax in OECD countries alone would be likely to improve the global environment. Appendix A of this chapter provides more detail about the model and the base case.

MODELING APPROACH

The results we present are based on a set of simulations we conducted using a detailed model of the U.S. economy that was designed specifically to examine the effects of energy and environmental policies. One feature of our approach that distinguishes it from many others is that we use a general equilibrium model. General equilibrium models are constructed by dividing the economy into a collection of interdependent sectors, which interact through markets for goods and services. (The behavior of each sector is represented by an appropriate submodel.) When a new policy, such as a carbon tax, is introduced, prices and wages adjust until demands and supplies are equated in every market and the economy reaches equilibrium.

Our model is composed of thirty-five producing sectors, a consumer sector, an investment sector, a government sector, and a foreign sector. Appendix A presents an overview of the model by describing the submodels used to represent each of these sectors. It also discusses our base case simulation.[1]

THE COST OF STABILIZING EMISSIONS

Somewhat surprisingly, the United States has had an extended period of stable carbon dioxide emissions once before: from 1972 to 1985. During that period, high oil prices reduced energy demand and lowered carbon dioxide emissions substantially. The relationship between oil prices and carbon emissions can be seen by a comparison of historical oil prices, shown in figure 8.1, with the history of U.S. carbon emissions, shown in figure 8.2. The large increases in oil prices in 1974 and 1979 led to drops in the trend rate of emissions growth. However, this reduction came at a very high price: the oil price shocks reduced U.S. GNP growth by 0.2 per-

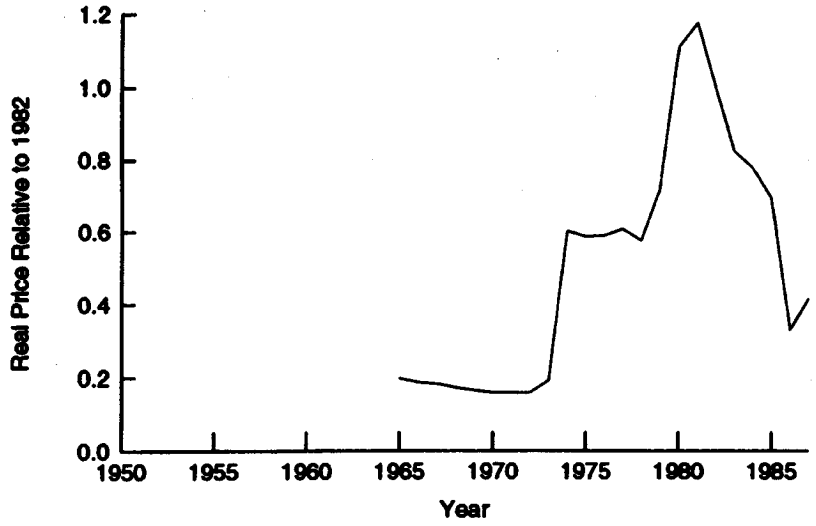

Figure 8.1. Real price of oil.

cent per year from 1974 to 1985.[2] The lesson from this episode is that a 0.2 percentage point of annual GNP growth is an upper bound on the cost of stabilizing U.S. carbon dioxide emissions.

The policy most often proposed for reducing carbon emissions is a carbon tax.[3] A carbon tax would be applied to fossil fuels used for combustion in proportion to the carbon dioxide the fuels emit when burned. From the standpoint of economic efficiency, a carbon tax is the ideal way to reduce carbon dioxide emissions because it is very close to a tax on the externality itself: if firms and individuals must pay to emit carbon dioxide, they will emit less. A carbon tax would stimulate users to substitute other inputs for fossil fuels and to substitute fuels with lower carbon content, such as natural gas, for high-carbon fuels such as coal.

Fossil fuels differ substantially in both price and the amount of carbon dioxide produced per Btu of energy (see table 8.1). One Btu from oil, for example, costs more than three times as much as a Btu from coal but produces only 80 percent of the carbon dioxide. The least carbon-intensive fuel is natural gas: one Btu of natural gas produces only about half as much carbon dioxide as does one Btu of coal. Together, the differences in price and carbon content mean that a carbon tax would produce very different percentage changes in the prices of the fuels. A $10 per ton tax on carbon would raise the price of coal by 29 percent, the price of oil by 6 percent, and the price of gas by almost 7 percent.

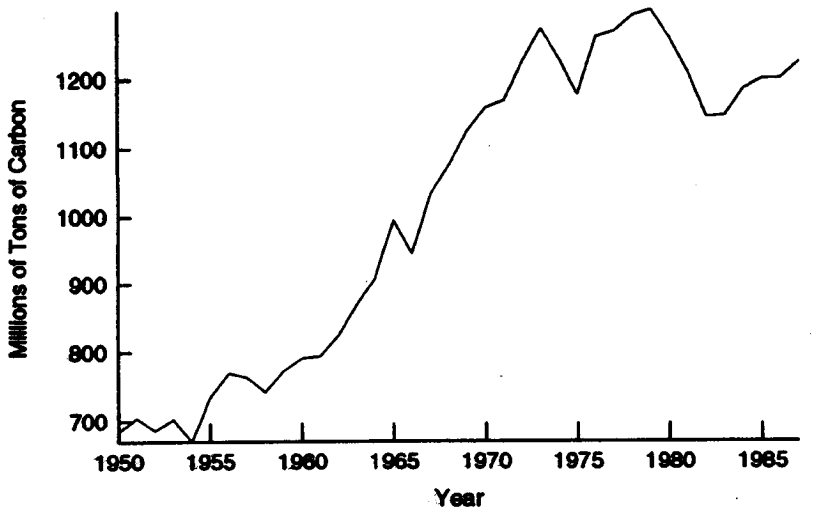

Figure 8.2. U.S. carbon emissions.

TABLE 8.1

Relative Carbon Content of Fossil Fuels

Characteristic	Fuel: Coal (ton)	Fuel: Oil (bbl)	Fuel: Gas (mcf)
Million Btu per unit	21.94	5.80	1.03
Tons of carbon per unit	0.649	0.137	0.016
Carbon per million Btu			
Tons	0.030	0.024	0.016
Percentage relative to coal	100	80	54
Approximate price before tax ($)			
Per unit of fuel	22	21	2.4
Per million Btu	1.00	3.62	1.36
Tax equal to $10 per ton of carbon ($)			
Per unit of fuel	6.49	1.36	0.16
Per million Btu	0.30	0.24	0.16
Percentage increase per unit	29.50	6.48	6.67

The carbon tax policy that has been debated most widely would impose a tax large enough to limit emissions to 1990 rates. To measure the effect of such a policy on the United States, we constructed a simulation in which the carbon tax rate was allowed to vary from year to year but was always chosen to be exactly enough to hold U.S. carbon dioxide emissions at their 1990 value of 1,576 million tons.[4] We returned the revenue raised

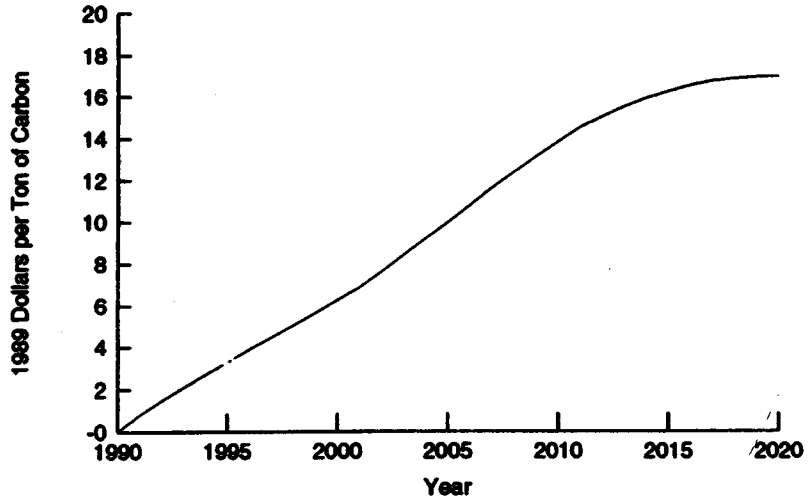

Figure 8.3. Carbon tax under stabilization.

by the tax to households as a lump sum rebate. Without the carbon tax, emissions would increase over time, so the tax grows gradually over the next few decades (see figure 8.3). By 2020 the U.S. population is likely to crest and emissions growth will begin to slow, reducing the rate of carbon tax growth.[5]

The tax would produce significant reductions in carbon emissions, as shown in figure 8.4. By 2020 emissions are 16 percent lower than they would have been without the tax. The tax also produces considerable revenue: $31 billion annually by 2020 (all dollar amounts are in 1990 prices).

The principal direct effect of the tax is to increase purchasers' prices of coal and crude oil. By 2020, for example, the tax reaches $22.71 per ton of carbon. As shown in table 8.2, this amounts to a tax of $14.75 per ton of coal, $3.10 per barrel of oil, or $0.37 per thousand cubic feet of gas. The tax would increase the prices of fuels but leave other prices relatively unaffected (see figure 8.5). The price of coal would rise by 47 percent, the price of electricity would rise by almost 7 percent (coal accounts for about 13 percent of the cost of electricity), and the price of crude oil would rise by around 4 percent. The prices of refined petroleum and natural gas utilities would rise because of the tax on the carbon content of oil and natural gas.

Changes in the relative prices for fuels would affect demands for each good and lead to changes in industry outputs (see figure 8.6). In the model, most sectors show only small changes in output. Coal mining is an

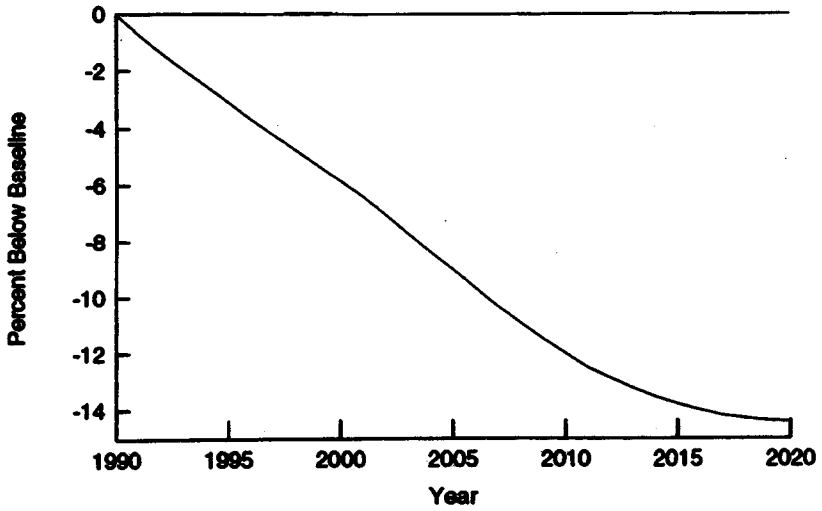

Figure 8.4. Carbon emissions under stabilization.

TABLE 8.2

Selected Results for the Stabilization Scenario, 2020

Variable	Unit	Value
Carbon emissions	% change	–16.12
Carbon tax	$ per ton	22.71
Tax on coal	$ per ton	14.75
Tax on oil	$ per bbl	3.10
Tax on gas	$ per mcf	0.37
Price of capital	% change	0.40
Capital stock	% change	–0.83
Tax revenue	$ (in billions)	31.41
Real GNP	% change	–0.55
Coal price	% change	46.99
Coal output	% change	–29.28
Electricity price	% change	6.60
Electricity output	% change	–6.17
Oil price	% change	4.45
Oil output	% change	–3.90

exception: its output falls by almost 30 percent. Coal is strongly affected for three reasons. First, coal emits more carbon dioxide than oil or natural gas per unit of energy produced. Thus, the absolute level of the tax per unit of energy content is higher on coal than on other fuels. Second, the tax is very large relative to the base case price of coal for purchasers: at the

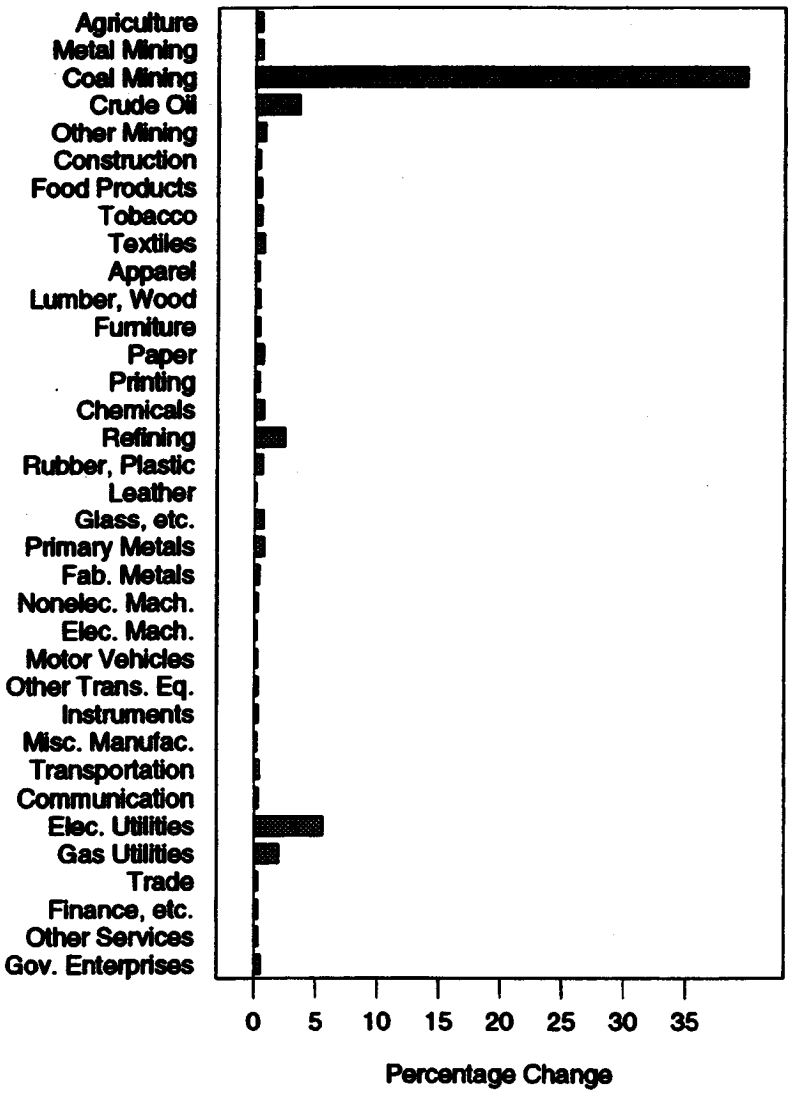

Figure 8.5. Effect on prices in 2020.

mine mouth, the tax would increase coal prices by around 50 percent. (In contrast, oil is far more expensive per unit of energy, so that in percentage terms its price is less affected by the tax. The price of crude oil rises only about 10 percent.) Third, the demand for coal is relatively elastic. Most coal is purchased by electric utilities, which can substitute other fuels for

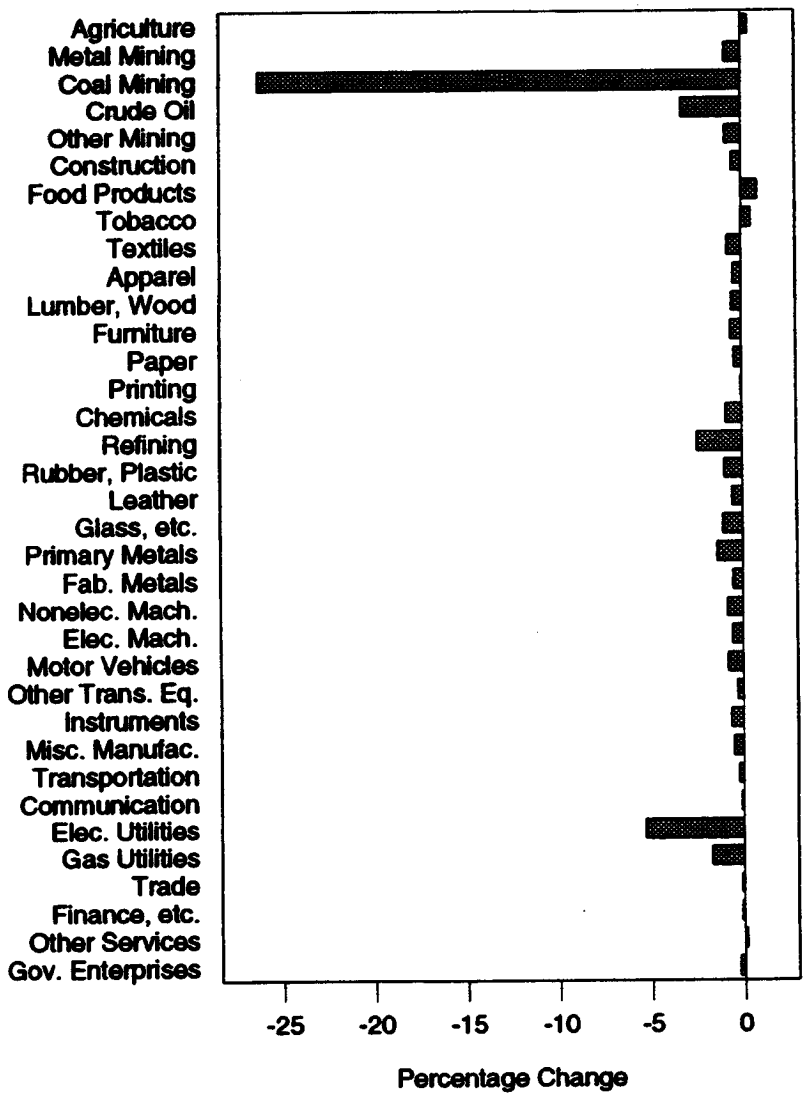

Figure 8.6. Effect on output in 2020.

coal when the price of it rises. Moreover, the demand for electricity itself is relatively elastic, so that when the price of electricity rises, demand for electricity (and hence demand for coal) falls substantially.

Outside the energy industry, the main result of the carbon tax would be to increase the prices of electricity, refined petroleum, and natural gas,

each by a few percentage points. This rise in prices would have two effects. First, higher energy prices would mean that capital goods, which are produced through the use of energy, would become more expensive. Higher prices for capital goods would mean a slower rate of capital accumulation and lower GNP in the future. Second, higher energy prices would discourage technical change in industries in which technical change tends to increase energy intensity. Together, these two effects would cause the capital stock to drop by 0.7 percent and GNP to fall by 0.5 percent by 2020 (relative to the base case). Average annual GNP growth over the period from 1990 to 2020 would be 0.02 percentage points lower than in the base case. About half of this is due to slower productivity growth and half is due to reduced capital formation.

GREATER REDUCTIONS IN EMISSIONS

Even if emissions were stabilized at 1990 rates, atmospheric concentrations of carbon dioxide would continue to rise for decades. Thus, holding emissions at 1990 rates would not prevent further global warming. This observation has led many observers to call for much larger cuts in carbon dioxide emissions. To see how the economy would be affected by a more stringent carbon dioxide control policy, we constructed a second carbon tax scenario in which emissions were required to decrease 20 percent below 1990 levels by 2010. (Key results are shown in table 8.3; results from the stabilization simulation are also shown for comparison.)

Increasing the stringency of the policy increases its cost substantially. Moving from the stabilization scenario to the 20-percent reduction case doubles the effect of the policy: emissions fall by 32.90 percent instead of by 16.12 percent. However, this reduction is achieved at the cost of tripling both the carbon tax and the loss of output. The more stringent policy has a relatively larger effect on sectors other than coal mining. In particular, doubling the emissions reduction does not cause the reduction in coal output to double. Coal users, particularly electric utilities, find it increasingly difficult to substitute other fuels for coal. Thus, the larger reduction in carbon emissions requires a larger reduction in oil use. Under the 20-percent reduction case, the drop in oil use is three times what it was under stabilization.

We determined the economy's cost curve for a variety of emissions targets. The results are summarized in figure 8.7, which shows the reduction in U.S. GNP in 2020 as a function of the percentage by which emissions are below 1990 levels. The reduction of emissions by more than 20

TABLE 8.3

Selected Results for Two Emissions Targets

Variable	Unit	Reduce by 20%	Stabilize at 1990 levels
Carbon emissions	% change	-32.90	-16.12
Carbon tax	$ per ton	74.49	22.71
Price of capital	% change	1.10	0.40
Capital stock	% change	-2.35	-0.83
Tax revenue	$ (in billions)	82.52	31.41
Real GNP	% change	-1.71	-0.55
Coal price	% change	149.86	46.99
Coal output	% change	-55.03	-29.28
Electricity price	% change	19.46	6.60
Electricity output	% change	-16.43	-6.17
Oil price	% change	15.06	4.45
Oil output	% change	-12.35	-3.90

percent causes large losses in GNP. To put these numbers in perspective, stabilizing the atmospheric concentration of carbon dioxide, which would lead to an eventual stabilization of temperature, would require reducing emissions by 50 percent relative to 1990, a very costly policy.

USE OF CARBON TAX REVENUE

Any tax large enough to reduce carbon dioxide emissions significantly will raise an enormous amount of revenue. In the simulations above, the tax produces $30 to $80 billion a year. Precisely how this revenue is used will have a large effect on the overall economic cost of slowing global warming. In particular, if the revenue were used to reduce distortionary taxes elsewhere in the economy, or if it were used to lower government budget deficits, there would be large welfare gains, which would offset some or all of the welfare losses associated with the carbon tax itself.

To determine how large this welfare improvement might be, we constructed three simulations in which the revenue from a carbon tax was used to reduce different taxes. In each simulation, we imposed a carbon tax of $15 per ton in 1990, with the rate rising by 5 percent annually in subsequent years. In the first simulation, the revenue was returned to households by a lump sum rebate; in the second, the revenue was used to lower taxes on labor, such as social security taxes; and in the third, it was used to lower taxes on capital, such as corporate income taxes.

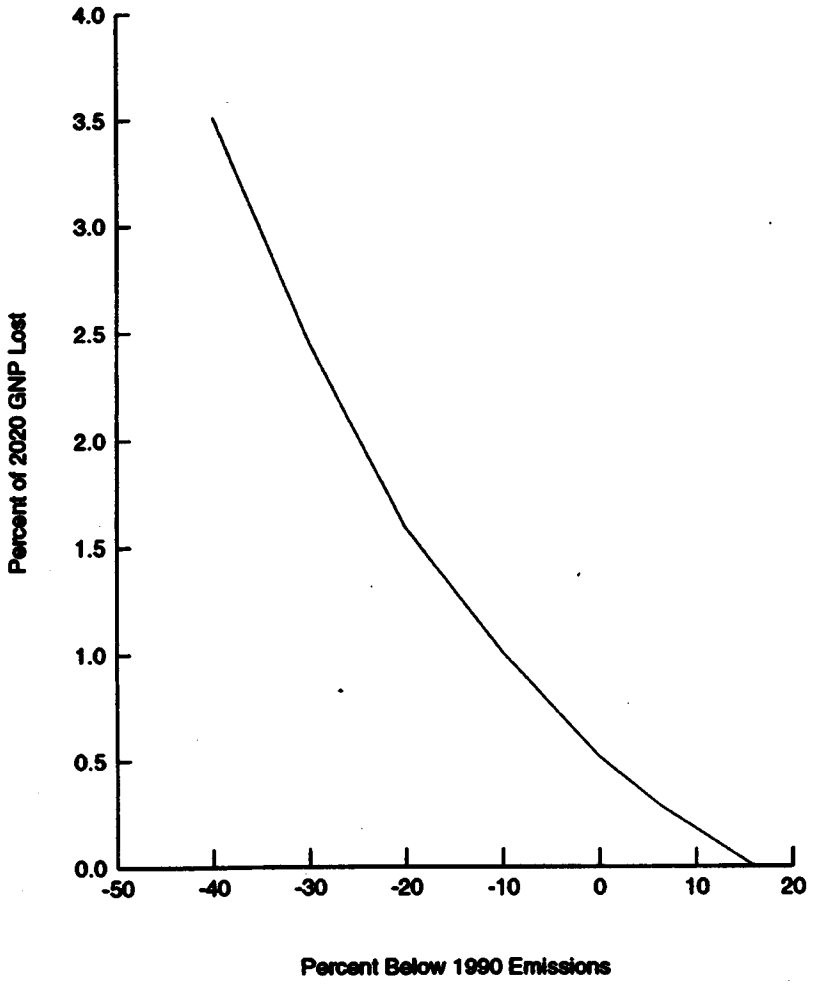

Figure 8.7. Cost of different emissions goals.

Our results show that the disposition of revenue from a carbon tax has a very significant effect on its overall impact on GNP (see table 8.4). In the lump sum case, output in 2020 drops by 1.70 percent relative to the base case. When the revenue is returned by lowering the tax on labor, the loss of GNP is less than half as much: only 0.69 percent. The improvement is due to an increase in employment brought about by the drop in the difference between before- and after-tax wages. If the revenue were returned as a reduction in taxes on capital, GNP would actually increase above its base case level by 1.10 percent. In this case, the gain is due to

TABLE 8.4

Selected Results for Revenue Experiments, 2020

		Revenue Policy		
Variable	Unit	Lump sum rebate	Labor rebate	Capital rebate
Carbon emissions	% change	-32.24	-32.09	-31.65
Carbon tax	$ per ton	64.83	64.83	64.83
Price of capital	% change	0.97	-1.86	0.23
Capital stock	% change	-2.13	-1.36	1.89
Tax revenue	$ (in billions)	79.65	79.82	80.35
Real GNP	% change	-1.70	-0.69	1.10
Coal price	% change	143.49	140.57	142.06
Coal output	% change	-54.14	-54.19	-53.45
Electricity price	% change	18.57	15.97	16.99
Electricity output	% change	-15.93	-15.37	-14.66
Oil price	% change	14.20	12.28	14.55
Oil output	% change	-11.92	-11.54	-11.39

accelerated capital formation generated by an increase in the after-tax rate of return on investment. These results suggest that a carbon tax would provide an opportunity for significant tax reform.

OTHER TAX POLICIES

The concentration of costs in the coal sector raises the possibility that the coal lobby would be able to block passage of a carbon tax in the U.S. Congress. As a result, two alternative taxes are sometimes proposed: a tax on the energy content of fossil fuels (a Btu tax) and an ad valorem tax on fuel use. (An example of an ad valorem fuel tax that has often been proposed is an increased tax on gasoline.) Like a carbon tax, both of the other taxes would operate by raising the cost of fuels and hence inducing fuel users to substitute away from fuel use. This reduction in energy use is often proposed as a goal for its own sake. In a separate paper (Jorgenson and Wilcoxen 1993), we compared energy and ad valorem taxes to a carbon tax and found that although carbon taxes have the largest effect on coal mining, they have the smallest overall effect on the economy as a whole. Energy taxes were fairly similar to carbon taxes but had a slightly lower impact on coal mining (a drop in output of 25.0 percent instead of 26.3 percent) and a slightly higher overall cost (a drop in GNP at 2020 of 0.6 percent instead of 0.5 percent). In contrast, ad valorem taxes fell much

TABLE 8.5

Effects of Different Tax Instruments, 2020

Variable	Unit	Instrument		
		Carbon tax	Btu tax	Ad valorem tax
Carbon emissions	% change	-14.4	-14.4	-14.4
Carbon tax	$ per ton	16.96	—	—
Btu tax	$ per million Btu	—	0.47	—
Ad valorem tax	%	—	—	21.6
Tax on coal	$ per ton	11.01	10.21	—
Tax on oil	$ per bbl	2.31	2.70	—
Tax on gas	$ per mcf	0.28	0.48	—
Tax revenue	$ (in billions)	26	31	53
Capital stock	% change	-0.7	-0.8	-1.4
Real GNP	% change	-0.5	-0.6	-1.0
Price of coal	% change	39.9	37.2	26.1
Quantity of coal	% change	-26.3	-25.0	-19.5
Price of oil	% change	3.6	5.0	12.8

more lightly on coal mining (a 19.5-percent drop in output rather than a 26.3-percent drop) at the expense of having a much greater effect on the rest of the economy through higher oil prices (a 1.0-percent drop in GNP instead of a 0.5-percent drop; see table 8.5).

DISTRIBUTIONAL EFFECTS

Carbon taxes are sometimes opposed on the grounds that they are regressive. It is certainly true that a carbon tax could have widely varying effects across households. However, it is not clear that the tax would be significantly regressive.[6] Poterba (1991) estimated the impact of a $100 per ton carbon tax on U.S. households with different levels of total expenditure. He concluded that the impact of a carbon tax would be slightly regressive by this measure, falling more heavily on households having low total expenditures. Classifying households by income rather than by expenditure makes the tax appear slightly more regressive. DeWitt, Dowlatabadi, and Kopp (1991) conducted a study with more regional detail and found that there would be substantial differences in economic impacts across different geographic regions.[7] Both Poterba and DeWitt, Dowlatabadi, and Kopp came to the conclusion that nonenergy prices would also change, so that a general equilibrium approach is required to assess the full impact. This approach has been taken by Jorgenson, Slesnick, and

Wilcoxen (1992), who found the tax to be mildly regressive, although the size of the effect varied across different consumer groups.[8]

INTERNATIONAL ASPECTS

Unlike many environmental problems, carbon emissions are a global externality, which makes the implementation of a carbon tax difficult for several reasons. First, the tax would have to be levied by individual governments, some of which might not be willing to participate. Although most OECD nations have now agreed that some limit should be placed on carbon dioxide emissions, many developing nations have been reluctant to adopt any carbon dioxide policy that might reduce their economic growth. Schelling (1992) suggested that this resistance poses an insurmountable obstacle to a unanimous international policy. A likely outcome is that any global carbon dioxide policy would be incomplete: OECD nations would adopt the policy, while developing nations would not.

A tax with only partial international coverage could be vitiated by the movement of energy-intensive industries away from participating countries to other nations. In fact, Hoel (1991) has shown that if nonparticipating nations have inefficient energy technologies, it is theoretically possible for such a policy to result in a net increase in world carbon dioxide emissions. To date, however, only a modest amount of empirical research has been done on how an incomplete carbon policy would affect patterns of international trade. The principal study was conducted by Felder and Rutherford (1992), who found that the amount of redirected emissions could be considerable. An OECD carbon tax could reduce OECD oil demand enough to lower the world price of oil substantially. Lower world oil prices would lead, in the Felder-Rutherford model, to a large increase in oil demand by developing countries.

A second reason why the global nature of carbon dioxide emissions would make the implementation of a carbon tax difficult is that the point at which the tax is applied has important distributional effects. Whalley and Wigle (1990) noted that carbon taxes could be applied in several different ways, each achieving the same reduction in carbon dioxide emissions but having large differences in the distribution of costs.[9] A carbon tax large enough to reduce emissions substantially would raise an enormous amount of revenue. If the tax is applied at the point of production, it would be collected by the governments of producing countries. If the tax is applied to consumption, on the other hand, the revenue would flow

to governments of consuming nations. Since the revenues are likely to be large, this is an important issue.

CONCLUSION

In this chapter, we examined the likely economic effects of a carbon tax. We find that a carbon tax will reduce U.S. GNP relative to its level in the absence of the tax, because a carbon tax will raise the price of energy. Moreover, the effects of the tax will be very similar to the effects of a tax placed solely on coal. Of all fossil fuels, coal is the least expensive per unit of energy and produces the most carbon dioxide when burned. Thus, a tax levied on carbon dioxide emissions will raise the cost of coal-based energy far more in percentage terms than the price of energy derived from oil or natural gas. In response to this price change, the demand for coal will fall substantially. The demands for oil and natural gas will also decline, but by much smaller percentages.

Almost all of the coal consumed in the United States is used to generate electric power. As the price of coal rises, electric utilities will convert some generating capacity to other fuels. However, substitution possibilities are fairly limited, particularly in the short run, so the tax will raise the price of electricity significantly. Consumers and firms will devote more effort to conserving energy by substituting other inputs for electricity, leading to a fall in electricity demand. Higher energy prices will lead to slower productivity growth, reduced capital formation, and a reallocation of labor to lower wage industries, all of which will cause GNP to be lower than it would have been in the absence of the tax.

The tax rate needed to achieve a fixed absolute emissions target, such as maintaining emissions at 1990 levels, will depend on how fast emissions grow in the absence of the tax. Baseline emissions growth, in turn, will depend on the rate of productivity growth, the rate of capital accumulation, the rate of growth of the labor force, any energy-saving biases in technical change, and the path of world oil prices. More rapid economic growth will generally lead to higher baseline emissions and will thus require higher tax rates if emissions are to be held at a fixed absolute level. Moreover, deeper absolute cuts in emissions will require sharply increasing tax rates.

A carbon tax large enough to have much effect on emissions would raise tens to hundreds of billions of dollars annually. Thus, it would provide an opportunity for significant tax reform, and this reform could soften the effect of the tax on GNP. If the revenue was used to reduce distortionary

taxes elsewhere in the economy, the impact of the tax on GNP would be reduced. In fact, it is possible that GNP would actually increase if the revenue was used to reduce taxes on capital.

Finally, several additional observations need to be kept in mind regarding carbon taxes. First, the United States did, in fact, stabilize its carbon dioxide emissions during the 1970s and early 1980s when oil prices were very high. However, the cost in terms of lost GNP was much higher than if emissions had been controlled by a carbon tax. Costs would also be much higher if other inefficient instruments, such as a Btu or an ad valorem tax, were used instead of a carbon tax. Second, the distributional effect of a carbon tax will be regressive, but only very slightly. Third, if an international carbon tax were imposed in some countries but not in others, changes in trade patterns would shift carbon-intensive activities to countries in which they were not taxed, compromising the original policy to some extent.

APPENDIX A

Overview of the General Equilibrium Model and Base Case

This appendix presents an overview of the general equilibrium model and base case that we used to estimate the effects of a carbon tax on the United States. The model includes thirty-five producing sectors, a consumer sector, an investment sector, a government sector, and a foreign sector. For more detail on the specification of the model or the base case simulation, see Jorgenson and Wilcoxen (1990).

Production

In the model, production is disaggregated into the thirty-five industrial sectors listed in table A.1. Most of these industries match two-digit sectors in the Standard Industrial Classification. Each industry produces a primary product and may produce one or more secondary products. This level of industrial detail makes it possible to measure the effect of changes in tax policy on relatively narrow segments of the economy. Since most anthropogenic carbon dioxide emissions are generated by fossil fuel combustion, a disaggregated model is essential for capturing differences in the response of each sector to a carbon dioxide control policy.

The behavior of each industry is derived from an industry-specific nested cost function. At the highest level, the cost of each industry's output is assumed to be a transcendental logarithmic (translog) function

TABLE A.1

Industry Definitions

Number	Description
1	Agriculture, forestry, and fisheries
2	Metal mining
3	Coal mining
4	Crude petroleum and natural gas extraction
5	Nonmetallic mineral mining
6	Construction
7	Food and kindred products
8	Tobacco products
9	Textile mill products
10	Apparel and other textile products
11	Lumber and wood products
12	Furniture and fixtures
13	Paper and allied products
14	Printing and publishing
15	Chemicals and allied products
16	Petroleum refining
17	Rubber and plastic products
18	Leather and leather products
19	Stone, clay, and glass products
20	Primary metals
21	Fabricated metal products
22	Machinery, except electrical
23	Electrical machinery
24	Motor vehicles
25	Other transportation equipment
26	Instruments
27	Miscellaneous manufacturing
28	Transportation and warehousing
29	Communication
30	Electric utilities
31	Gas utilities
32	Trade
33	Finance, insurance, and real estate
34	Other services
35	Government enterprises

of the prices of capital services, labor, energy, and materials. The price of energy, in turn, is assumed to be a translog function of prices of coal, crude petroleum, refined petroleum, electricity, and natural gas, while the price of materials is a translog function of the prices of all other intermediate goods. Given this structure, we derived demand equations for capital services, labor, and intermediate inputs for each of the industries.

We estimated the parameters of each industry submodel econometrically through the use of a set of consistent interindustry transactions tables constructed for the purpose. The tables describe the U.S. economy for the period 1947 through 1985. (See Jorgenson and Wilcoxen, 1990, for details on how the data set was constructed.) Estimating the production parameters over a long time series ensures that each industry's response to changes in prices is consistent with historical evidence.

An unusual feature of our model is that productivity growth is determined within the model. Other models that have been used to study global warming—for example, Manne and Richels's (1992)—take productivity growth to be exogenous. In our model, the rate of productivity growth in each industry is determined endogenously as a function of input prices. In addition, each industry's productivity growth may shift it toward some inputs and away from others. Biased productivity growth is a common feature of historical data but is often ignored when production is modeled. By allowing for biased productivity growth, our model is able to capture the evolution of industry input patterns much more accurately.

Consumption

The model represents consumer behavior by assuming that households follow a three-stage optimization process. At the first stage, each household allocates full wealth (the sum of financial and human wealth, plus the imputed value of leisure time) across different periods. We formalized this decision by introducing a representative agent that maximizes an additive intertemporal utility function subject to an intertemporal budget constraint. The portion of full wealth allocated to each period is called "full consumption." At the second stage, households allocate each period's full consumption to goods and leisure in order to maximize an indirect utility function. This generates demands for leisure and goods as functions of prices and full consumption. The demand for leisure implicitly determines labor supply, while the difference between current income and consumption of goods implicitly determines savings.

The third stage of the household optimization problem is the allocation of total expenditure among capital services, labor services, and the thirty-five commodities. At this stage, we relaxed the representative consumer assumption in favor of the approach used by Jorgenson, Lau, and Stoker (1982) that derives separate systems of demand functions for households with different demographic characteristics. The model distinguishes among 1,344 household types according to demographic characteristics such as the number of household members and the geographic region in which the household is located. The

spending patterns of each household type are derived from a hierarchial tier-structured indirect utility function. This generates household demands for individual commodities.

As with production, the parameters of the behavioral equations for all three stages of our consumer model are estimated econometrically. Our household model incorporates extensive time-series data on the price responsiveness of demand patterns by consumers and also makes use of detailed cross-section data on the effects of demographic characteristics on consumer behavior. In addition, an important feature of our approach is that we do not require that the pattern of household demands be independent of income. (Formally, we do not impose the restriction that the utility function be homothetic.) As total expenditure increases, spending patterns may change even in the absence of price changes. This method captures an important feature of cross-sectional expenditure data that is often ignored.

INVESTMENT AND CAPITAL FORMATION

The model has a single capital stock, which is in fixed total supply in the short run. This capital is perfectly malleable and can be reallocated among industries and between industries and final users at zero cost. Thus, the price of a unit of capital services is equal in every industry, and there is a single economywide rate of return on capital.

In the long run, the supply of capital is determined by investment. Our investment model is based on the assumption that investors have rational expectations and that arbitrage occurs until the present value of future capital services is equated to the purchase price of new investment goods. This equilibrium is achieved by adjustments in prices and the term structure of interest rates. New capital goods are produced from individual commodities according to a model identical to those for the industrial sectors, so that the price of new capital depends on commodity prices. We estimated the behavioral parameters for new capital goods production using final demand data for investment over the period 1947–1985. Thus, the model incorporates substitution among inputs in the composition of the capital.

GOVERNMENT AND FOREIGN TRADE

The two remaining parts of the model are the government and foreign sectors. To specify government behavior, we began by computing total government spending on goods and services. We started by assuming that tax rates would be fixed at current levels in the absence of changes in policy. We then applied these rates to taxable transactions in the economy

to obtain total tax revenue. To this we added the capital income of government enterprises and non–tax receipts to obtain total government revenue. (The capital income of government enterprises is endogenous, while non–tax receipts are exogenous.) Next we assumed that the government budget deficit can be specified exogenously and added the deficit to total revenue to obtain total government spending. To arrive at government purchases of goods and services, we subtracted interest paid to holders of government bonds together with transfer payments to domestic and foreign recipients. We then allocated spending among commodity groups according to fixed shares constructed from historical data.

In modeling the foreign sector, we began by assuming that imports are imperfect substitutes for similar domestic commodities. The mix of goods purchased by households and firms reflects substitution between domestic and imported products. We estimated the price responsiveness of this mixture econometrically from historical data. In effect, each commodity is assigned a separate elasticity of substitution between domestic and imported goods. Since the prices of imports are given exogenously, intermediate and final demands implicitly determine the quantity of imports of each commodity.

Exports are determined by a set of isoelastic export demand equations, one for each commodity, that depend on foreign income (which we take to be exogenous) and the foreign prices of U.S. exports. Foreign prices are computed from domestic prices by adjusting for subsidies and the exchange rate. The demand elasticities in these equations are estimated from historical data. Without an elaborate model of international trade, it is impossible to determine both the current account balance and the exchange rate endogenously. We chose to make the exchange rate endogenous and the current account exogenous.

The Base Case

To assess the effect of a carbon tax, we first determined the future path of the U.S. economy in the absence of the tax. To construct such a scenario, which we call a "base case," we adopted a set of default assumptions about the time path of each exogenous variable in the absence of changes in government policy. Since savings and investment are determined by the expectations of households and investors, we specified the values of the model's exogenous variables far into the future. Through the period 1990–2050, we forecast values of the exogenous variables on the basis of their behavior in the sample period. After 2050 we assumed the variables remain constant at their 2050 values to allow the model to converge to a steady state by the year 2100.

Our projections for 1990–2050 were made as follows. First, all tax rates were set to their values in 1985, the last year in our sample period. Next, we assumed that foreign prices of imports in foreign currency remain constant in real terms at 1985 levels. We then projected a gradual decline in the government deficit through the year 2025, after which the nominal value of the government debt is maintained at a constant ratio to the value of the national product. Finally, we projected the current account deficit by allowing it to fall gradually to zero by the year 2000. After that, we projected a current account surplus sufficient to produce a stock of net claims on foreigners by the year 2050 equal to the same proportion of national wealth as in 1982. That is, we projected the United States to return to its 1982 position of being a net lender to the rest of the world.

Some of the most important exogenous variables are those associated with the growth of the U.S. population and corresponding changes in the economy's time endowment. We projected population by age, sex, and educational attainment through the year 2050 using demographic assumptions consistent with the Social Security Administration's projections. After 2050 we held population constant, which is roughly consistent with social security projections. In addition, we projected the educational composition of the population by holding the level of educational attainment constant beginning with the cohort reaching age 35 in the year 1985. We transformed our population projection into a projection of the time endowment by assuming that the pattern of relative wages across different types of labor remains as it was in 1985. Since capital formation is endogenous in our model, our projections of the time endowment effectively determine the size of the economy in the more distant future.

ACKNOWLEDGMENTS

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NOTES

1. For more detail on the specification of the model or the base case simulation, see Jorgenson and Wilcoxen (1990).
2. For a more complete discussion, see Jorgenson and Wilcoxén (1993).

3. A carbon tax was first proposed by Nordhaus (1979).
4. A tax that varies from one year to the next in order to keep carbon emissions absolutely constant is a useful analytical device but is not a likely policy. The tax could not be adjusted quickly enough to keep emissions constant in every year.
5. Our population projection is based on forecasts made by the U.S. Social Security Administration in which population growth approaches zero early in the next century.
6. The distributional effects of a carbon tax have been examined by Poterba (1991), DeWitt, Dowlatabadi, and Kopp (1991), Jorgenson, Slesnick, and Wilcoxen (1992), and by Schillo et al. (1992).
7. DeWitt, Dowlatabadi, and Kopp (1991) used a detailed econometric model of U.S. household energy consumption to estimate the response of energy consumption patterns to the tax.
8. Jorgenson, Slesnick, and Wilcoxen (1992) used a detailed, econometrically estimated intertemporal general equilibrium model to measure the lifetime incidence of a carbon tax on consumers in different demographic groups.
9. Whalley and Wigle (1990) used a dynamic global general equilibrium model to assess the distributional effects of various carbon dioxide abatement policies.

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GLOBAL CLIMATE CHANGE

THURSDAY, JULY 17, 1997

U.S. SENATE,
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS,
Washington, DC.

INTERNATIONAL POLICY REVIEW

The committee met, pursuant to recess, at 9:38 a.m. in room 406, Senate Dirksen Building, Hon. John H. Chafee (chairman of the committee) presiding.

Present: Senators Chafee, Inhofe, Baucus, Kempthorne, Reid, and Wyden.

OPENING STATEMENT OF HON. JOHN H. CHAFEE, U.S. SENATOR FROM THE STATE OF RHODE ISLAND

Senator CHAFEE. This morning we have, as is not infrequent, some challenges as far as time goes. What I'd like to do this morning is have our opening statements, which I hope will be rather brief, and then we'll vote. The first vote is on now. I believe the leader has scheduled three votes.

I noticed Secretary Wirth isn't here yet, but I certainly presume he'll be here when we finish our statements.

A week ago today, the committee received testimony from a distinguished panel of witnesses on the science and economics of global climate change. This morning we hope to learn more about how the Administration has interpreted the current scientific and economic understanding of the climate change issue to form its domestic and international policies, how is this all influencing us.

We will also receive views from two very knowledgeable representatives of the business community.

What we did learn last week from our witnesses? I must say it didn't all come out like the blinding light that hit Paul on the road to Damascus, but information was there if we looked hard enough. Many left the hearing even more sure that there are too many uncertainties to commit the United States to additional or legally binding greenhouse gas emission reductions.

Others may now be further convinced that serious climate change risks have been demonstrated sufficiently and that the time for meaningful, preventive action is now.

Individuals possessing sound reason and good intent, of which this committee has 18, could plausibly arrive at either conclusion. That's a judgment call. Those of us in government and here on this committee have to advance with the best possible information.

What are the facts? First, energy from the sun warms the Earth. Second, greenhouse gases in the atmosphere trap heat from the Earth that would otherwise radiate out into space. Third, greenhouse gases make the Earth warmer than it otherwise would be.

Fourth, water vapor is the most abundant, natural greenhouse gas. Fifth, greenhouse gases emitted by human activities are altering the pre-industrial composition of the atmosphere. Indeed, the concentration of carbon dioxide in the atmosphere has increased from about 280 parts per million 200 years ago to about 360 ppm today.

Importantly, the concentrations will not absolutely halt at 360 ppm. We will observe a doubling of pre-industrial concentrations sometime in the early part of the next century unless we take action.

Sixth, all nations are contributing to this buildup of greenhouse gases. No one Nation acting alone can effectively address this matter. Seventh, the United States is the largest greenhouse gas emitter in absolute and in per capita terms. China is the second largest greenhouse gas emitter in absolute, but on a per capita basis, emits one-tenth of U.S. emissions. Eighth, we have measured one degree of Fahrenheit temperature increase globally over the past 100 year.

Finally, on the economic side, it is a fact that limiting carbon dioxide emissions will mean significant changes in energy use and energy sources.

The question is, has science provided enough information on the relationship between these facts and actual changes in the climate to warrant further action? Obviously, the Administration has made its conclusion.

The United States and 160 other nations are negotiating changes to the existing 1992 United Nations Framework Convention on Climate Change. These changes, if agreed to, could require specific, legally binding, greenhouse gas emission reductions commitments for the post-2000 period. These international negotiations are to culminate at the third conference of the parties in Kyoto in December of this year.

Should we be signatories to a Kyoto agreement? What role should the developing countries play? What kind of emission reduction requirements are appropriate? What are the likely economic trade, competitiveness and job impacts? What are the likely environmental impacts of acting or not acting? How will such an international agreement be implemented domestically?

Finally, is it possible to embark upon a "low regrets," or "no regrets" strategy which would minimize economic damage or even improve our economic performance while responsibly reducing the threat of climate change? Can we do some things that are cost-effective, regardless of whether we believe in reducing the treat of climate change, but indeed, will reduce the threat of climate change? For instance, we talked the other day about a certain type of bulb in our lights.

These are other topics will be our focus today.

Senator Baucus.

OPENING STATEMENT OF HON. MAX BAUCUS, U.S. SENATOR FROM THE STATE OF MONTANA

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

I have just a few brief remarks and observations from last week.

No. 1, the scientists last week presented what I thought was quite solid evidence and a thoughtful argument that future changes in our climate caused by human activity is a potentially serious, if not absolutely certain, outcome.

To me, that means the potential consequences are too serious to ignore and if we begin to make modest steps now to curtail greenhouse gas emissions, we may start making progress toward that goal without encountering serious economic disruptions.

As with many issues around here, our task is to find the right balance between maximizing the benefits of a policy and minimizing any adverse consequences from it. As we were told last week, the sooner we start, the better this country will be able to achieve that result.

My second point is that if we are to succeed in limiting worldwide emissions and CO_2 and other greenhouse gases, we must have greater participation by at least the major developing countries. After all, this is called global climate change. If the major global players are not part of the solution, the prospects for success will be slim.

Perhaps this is an area in which we need to broaden our thinking. I've spent a good deal of time looking at China's role in the world, particularly from the trade standpoint. The United States has a lot of issues to deal with China on, some issues on which we have fundamental disagreements, but there are many others with China on which we share mutual interest. Climate surely is one of them.

China has more people potentially at risk from rising sea levels and violent weather than any other nation. It also has a desperate need to increase its domestic energy supplies. If there is no change, China will be contributing a full one-third of the additional greenhouse gas emissions in the world over the next 20 years, one-third.

Looking at the broad array of issues on the United States-China table, we should be able to find ways to gain their support on this issue. As I've said many times, our disagreements with China should not stop us from engaging with them on issues where we can both make some progress.

Finally, Mr. Chairman, whatever our ultimate policy on climate change will be, it needs the support of the American people. I believe there is a compelling case to be made and it's why I welcome the President's decision to become more personally involved.

The toughest issues for democracies to handle are those in which the threat to society builds gradually but inexorably over time. We deal well with immediate crises and I hope it will not take such an event to spur action on this one.

Senator CHAFEE. Thank you, Senator.

Senator Inhofe.

OPENING STATEMENT OF HON. JAMES M. INHOFE, U.S. SENATOR FROM THE STATE OF OKLAHOMA

Senator INHOFE. Thank you, Mr. Chairman.

I do have a more lengthy statement that I will submit for the record, but I want to mention a couple of things that do concern me.

The Clean Air Subcommittee has already held one hearing on climate change. One of the things that concerns me is I think the disingenuous way we've gotten information and treatment from the Administration. I have a list of contradictory statements that have been made. I'll only mention one of them and then submit the rest of them in my opening statement.

In June 1996, Mr. Palmeritz, who is an Assistant Secretary over at the State Department, made the statement in response to the question "Are we going to agree to a legally binding instrument in Geneva?," "Are we going to agree to a legally binding instrument in Geneva? No way." One month later, Secretary Wirth, you announced that the United States supported a legally binding emissions target.

This concerns me, the discrepancies that we are getting in statements from the various departments.

I would like to just, in one sentence, outline five conclusions that I felt we came to in our first subcommittee hearing, Mr. Chairman, on this subject.

No. 1, while there is a large body of scientific research, there is much controversy and disagreement and the scientific facts are being misrepresented by the Administration and the press.

No. 2, we don't know how much human activity has influenced the climate. One scientist said less than 6 percent.

No. 3, if you look at satellite data, we are not sure if there has been any global warming.

No. 4, even if we eliminate all manmade emissions, it may not have a noticeable impact on the environment and the treaty may only eliminate emissions here in the United States and not the entire world.

No. 5, when asked, all five witnesses—these are the scientific witnesses—they stated that we would not have the uncertainties understood by this December when the Administration plans on making a decision regarding the treaty.

Thank you, Mr. Chairman. I'll be looking forward to asking some questions.

[The prepared statement of Senator Inhofe follows:]

PREPARED STATEMENT OF HON. JIM INHOFE, U.S. SENATOR FROM THE STATE OF OKLAHOMA

Thank you Mr. Chairman, I am glad you called today's hearing, it is important to hear from the Administration on this issue. Under Secretary Wirth has testified in many Congressional hearings over the last few years, and unfortunately he raises more questions than he answers, but I hope today will be different.

Last week at our science hearing on this issue, a number of points were made and I personally learned a great deal. I would like to summarize a few key observations from the hearing:

(1) While there is a large body of scientific research there is much controversy and disagreement and the scientific facts are being misrepresented by the Administration and the press.

(2) We don't know how much human activity has influenced the climate. One scientist said 6 percent.

(3) If you look at satellite data, we are not sure if there has been any global warming.

(4) Even if we eliminate all manmade emissions, it may not have a noticeable impact on the environment, and the Treaty may only eliminate emissions here in the United States, not the entire world.

(5) When asked, all five witnesses stated that we would not have the uncertainties understood by this December, when the Administration plans on making a decision regarding the Treaty.

I have read over the hearing records in the various congressional committees over the last few years and I am very disturbed by the way the Administration makes promises to Congress and then immediately ignores them in international meetings. I would like to offer a few examples.

In March 1995, in a House Commerce Hearing Congressmen Dingell and Schaefer raised concerns that new targets may not apply to all countries, on behalf of the Administration, Mr. Rafe Pomerance a Deputy Assistant Secretary at the State Department said "Our goal, Mr. Chairman, is that all parties participate in this next round of negotiations. We want to see that all governments participate and help define the post-2000 regime."

One month later the Administration signed onto the "Berlin Mandate" to review the commitments made to reduce the greenhouse gases and adopt targets for further reductions. The conference differentiated between developed and developing nations. This was clearly at odds with Congressmen Dingell and Schaefer's concerns and the Administration's assurances.

In June 1996, before a hearing, Mr. Pomerance stated, "Are we going to agree to a legally binding instrument in Geneva? No way." One month later in Geneva, Under Secretary Wirth announced that the United States supported a legally binding emissions target.

In September 1996 before the Commerce Committee, Assistant Secretary of State Eileen Claussen told Congressman Dingell that the United States would not be bound before we have completed the economic analysis and assessments. We learned this week that the Administrations efforts to analyze the economic effects has failed. The models they used did not work, and we will not understand the effect on our nation's economy before December.

I have to conclude based on the Hearing records that the performance of this Administration is somewhere between "misleading" and downright "untruthfulness". I hope today's witnesses can change this record, but I will have to reserve judgment to see if today's promises will be fulfilled.

Thank you Mr. Chairman.

Senator CHAFEE. We have about 4 minutes left on this vote and my suggestion is rather than racing through your statement, that we go over and vote and then come back and we'll hear your statement, Senator Kempthorne, and then proceed with the witnesses.

Senator KEMPTHORNE. If you don't mind, may I race?

Senator CHAFEE. We're certainly delighted to hear what you've got to say if you're conscious of 3½ minutes. The option is yours. I'm perfectly delighted to stay here. I was going to let you proceed in a more leisurely manner when the pearls you have to offer us will be easier observed in a calmer atmosphere.

Senator KEMPTHORNE. Mr. Chairman, I'd like to go ahead and do this, but if the others would like to go, I understand that, so I'll understand.

Senator CHAFEE. I'll wait with you.

OPENING STATEMENT OF HON. DIRK KEMPTHORNE, U.S. SENATOR FROM THE STATE OF IDAHO

Senator KEMPTHORNE. Mr. Chairman, I've always believed that fundamentally, we're all environmentalists. We all want a cleaner, healthier environment for our children and their children.

I've always believed that the best way to achieve that cleaner and healthier environment is not necessarily through more Federal regulation and mandates. I believe there will be better results achieved faster using incentives, flexible programs and voluntary incentives.

As I understand it, the push for more aggressive, global climate change policy is being driven by evidence that suggests that the global temperature has increased by one degree, although it's unclear whether or not human-caused activities are solely responsive for that increase. Nor do we know whether it's significant.

The assumption is that we should do something about it anyway, reduce or freeze greenhouse gas emissions to 1990 levels. While I won't dispute that conclusion here today, in light of the uncertainty, I think it's important that we not jump to impose more regulations on U.S. businesses risking jobs in our economy when we really don't know if we are truly addressing the problem.

We should also be concerned about what costs of any new policy will, in fact, be and who will bear them. Providing flexibility and greater opportunities for voluntary programs will go a long way to controlling unnecessary costs and increasing acceptance of any new policy.

Just as importantly, we should not put our U.S. industries at a competitive disadvantage with their competitors in international markets. Climate change is truly a global issue and the solution must be a global one as well.

If the United States is going to agree to mandatory reductions, our treaty partners, including developing countries, must also. That's only fair. Ultimately, the workability and cost of any new policy will be determined largely by the specific target levels and compliance schedules that the Administration negotiators decide to accept.

I look forward to hearing from the witnesses as we discuss this critically important issue.

Senator CHAFEE. We have to hasten over. Mr. Secretary, we will be back shortly. There are three votes, but they are 10-minute votes, so we will be back shortly.

There will be a brief recess.

[Recess.]

Senator CHAFEE. If we could have everyone's attention, we will start the hearing again.

We apologize for the interruptions. I guess nobody understands the interruptions better than the distinguished Assistant Secretary of State, a former colleague who served in this body with distinction.

We've completed all the statements and Mr. Secretary, go to it. We'd be interested to hear what you've got to say.

Secretary WIRTH. Thank you very much, Mr. Chairman.

Mr. Chairman, if you have any desired order, we might ask Dr. Yellen to lead off, if that would be all right.

Senator CHAFEE. That's fine. Go ahead, Dr. Yellen.

STATEMENT OF JANET YELLEN, CHAIR, COUNCIL OF ECONOMIC ADVISERS, NATIONAL ECONOMIC COUNCIL, EXECUTIVE OFFICE OF THE PRESIDENT

Ms. YELLEN. Good afternoon, Mr. Chairman, members of the committee.

I appreciate the opportunity to discuss with you today the economics of global climate change. In a speech to the United Nations in June, President Clinton emphasized that the risks posed by

global climate change are real and that sensible, preventive steps are justified.

This assessment accords with the views of more than 2,300 economists, including 8 Noble laureates, who signed the statement supporting measures to reduce the threat of climate change.

At this time, the Administration has not settled on a particular set of policies to reduce greenhouse gas emissions. Instead, the President indicated in his U.N. speech that he intends to engage in a discussion with all interested parties, Members of Congress and other elected officials, scientists, economists, business and labor leaders, about the problems posed by greenhouse gas accumulations and the costs and benefits of corrective action.

This discussion is intended to inform the Administration's decisionmaking process which will culminate in a U.S. policy position in the international negotiations in Kyoto in December of this year.

An important step in this, in any policy process, is determining the impact a policy will have on the American economy. President Clinton's top priority since his first days in office has been revitalizing the U.S. economy, creating jobs and investing in people and technology to enhance long-term growth, and we have made tremendous progress.

Any policy the President ultimately endorses on climate change will be informed by his commitment to sustaining a healthy and robust economy. In my testimony today, I'd like to describe some of the principle lessons that emerged from the voluminous literature, much of it relatively recent, on the economic impacts of policies to address global climate change.

Before I begin my discussion of the economic literature, however, I'd like first to emphasize the uncertainties that are associated with estimating both the costs and the benefits of reducing greenhouse gas emissions.

Just to provide some perspective, as you all know, it is quite difficult to gauge exactly what impact, for example, the balanced budget agreement will have on the U.S. economy's growth rate, levels of employment, interest rates and consumption over a period as long as the next 5 years.

With global climate change, it's orders of magnitude more difficult to gauge the effects of policies on the economy. We're concerned with not just the next 5 years and not just the American economy, but rather, with economic and physical processes that operate globally and over decades, if not centuries.

Both the costs and the benefits of climate protection are very difficult to quantify or predict with any certainty. So, in short, if anybody tells you that he or she has the definitive answer as to the costs and benefits of particular climate change policies, I would suggest that you raise your collective eyebrows.

Let me now turn to the economic literature and try to summarize what I think we know so far about this difficult topic.

The economic literature includes estimates using many different models to evaluate numerous alternative emission reduction strategies. In fact, because there are so many different models, economists initially faced difficulties in comparing results.

To solve this problem, thereby enabling meaningful comparisons, many economists have calibrated the various models by performing

a standardized simulation. Specifically, they've assessed the consequences of stabilizing greenhouse gas emissions at 1990 levels by 2010 or 2020.

Within the Administration, a staff level working group, the Interagency Analytical Team, has attempted to estimate some of the economic implications of climate change policies.

They took the emissions scenario that's most often used in the academic literature, that is stabilizing emissions at 1990 levels by 2010 as the starting point for their own analysis. I emphasize that this scenario is not Administration policy. Instead, it was picked to make comparison with other models easier.

This modeling effort produced some useful lessons, but as we found from peer reviewers' comments, it also suffered from some serious shortcomings. I think both the lessons and the shortcomings point to one clear conclusion which is that the effort to develop a model or small set of models that can give us a definitive answer concerning the economic impacts of a given climate change policy is futile, but we are left with a set of parameters and relationships that influence estimates of the impacts.

I understand that a draft of the staff analysis was given to this committee earlier this week, along with reviewers' comments. I would be happy to answer any questions you may have about this modeling effort. Let me say just a bit about the lessons.

The modeling efforts, both inside the Administration and outside, clearly indicate that economic analysis can do no more than estimate a range of potential impacts from particular policies and highlight how outcomes depend on underlying assumptions about how the economy works and the ways in which policy is implemented. I'd like to briefly summarize a few of the key lessons we've learned.

First, the magnitude of the cost of reducing greenhouse gas emissions in the various models depends crucially on a number of key assumptions about how the economy works. Essentially, the lesson is that the greater the substitution possibilities and the faster the economy can adapt, the lower the costs.

Second, costs depend critically on how emission reduction policies are implemented. It just boils down to this, if we do it dumb, it could cost a lot, but if we do it smart, it will cost much less and indeed, it could produce net benefits in the long run.

The over 2,300 signatories of the economist statement argued that any global climate change policy should rely on market-based mechanisms. These mechanisms allow for flexibility in both the timing and the location of emissions reductions, thereby minimizing the cost to the U.S. economy.

The economists concluded, "There are policy options that would slow climate change without harming American living standards and these measures may, in fact, improve U.S. productivity in the longer run."

The third lesson that emerges from a study of the economics of climate protection is that developing, as well as developed, countries must be part of the process. While developed countries are responsible for most of the greenhouse gas currently in the atmosphere, developing countries are starting to catch up.

The timetable for inclusion of developing countries is also important. The sooner the developing countries face incentives to move away from carbon-intensive energy sources, the less likely it is they will become dependent on those types of fuels to spur their own economic growth. In short, global problems require global solutions.

Let me wrap up by saying that policies to promote economic growth create jobs and improve the living standards and opportunities of all Americans have been and always will be the top priority of the President and the Administration.

In his remarks to the Business Roundtable on Global Climate Change, the President said, "Let's find a way to preserve the environment to meet our international responsibilities, to meet our responsibilities to our children, and grow the economy at the same time."

I believe that some of the lessons we've learned from the economics literature will help us achieve the President's goal.

Thank you. I'd be happy to answer any questions you may have.

Senator CHAFEE. Thank you very much.

Now what I'd like to do is proceed with Secretary Wirth.

Ms. YELLEN. I do have a longer statement I'd like to submit for the record.

Senator CHAFEE. That's fine. Do you have any urgency to leave?

Ms. YELLEN. No.

Senator CHAFEE. Why don't you go ahead?

Senator REID. Mr. Chairman.

Senator CHAFEE. Yes.

Senator REID. I ask unanimous consent that a copy of my statement be made a part of the record as if read.

Senator CHAFEE. Fine.

[The prepared statement of Senator Reid follows:]

PREPARED STATEMENT OF HON. HARRY REID, U.S. SENATOR FROM THE STATE OF NEVADA

Good Morning. I want to share a few thoughts on the science and economics of the global climate change debate. Although the committee has wisely chosen to hold two separate hearings on this subject this summer, one on science and economics, which was held last week and today's on the on-going international treaty negotiations, my comments cannot be so easily separated.

There is a discernible human influence on global climate. Since the dawn of the industrial age, the concentration of carbon dioxide in the atmosphere has risen by 30 percent. Most experts now agree that the build-up of greenhouse gases in the atmosphere due to the combustion of fossil fuels and other human activities is happening. To many this is a troubling phenomenon. Although we are not sure what the exact adverse consequences of this build-up will be, mere common sense dictates that we, at a *minimum*, begin preparing to deal with it.

The Senate approved the United Nations Framework Convention on Climate Change in 1993, which called for all signatory nations to adopt policies and programs to limit their greenhouse gas emissions on a voluntary basis. The United States had hoped to stabilize emissions in the year 2000 at 1990 levels. Unfortunately, we have fallen well short of that mark.

The United States is, at the moment, the world's biggest consumer of fossil fuels and producer of greenhouse gas emissions. As such, it is important that we must show international leadership in terms of analysis, research, and, if necessary, in reducing these emissions.

As part of the on-going international treaty negotiations, the Administration has moved towards supporting mandatory, legally binding limitations on greenhouse gases for the nations of the World. Within limits, I am supportive of these efforts.

Unfortunately, I share the concern of many of my colleagues that the current negotiations do not seem to require a firm time table for reductions from the nations of the developing world.

The United States currently emits more greenhouse gases than developing nations, such as China and India. However, this will not be the case for much longer, especially if the United States begins to curb our emissions. While I am not eager to perpetuate the poverty in these nations by mandating that they participate equally and immediately in making reductions, I have economic and competitive concerns about requiring nothing from them.

I cannot, in good faith, ask the citizens of Nevada and the rest of the Nation, who have worked very hard to develop and accommodate environmentally friendly transportation policies and clean industries, to now make more sacrifices without some guarantee that the developing nations will not make similar efforts soon.

In a global economy, we are often forced to compete with other nations that have different labor laws and practices than our own, different rules of resource protection, and yes, often weaker environmental laws. Unfortunately, cheap labor, wasteful resource use, and weak environmental laws often add up to a mighty competitive retail price.

On an issue of such wide-ranging economic impact and consequence, it is unfair to our citizens to let other nations do nothing while we make the necessary sacrifices.

Again, I absolutely acknowledge that the United States must do its part to try to avert any adverse climate change. We are a part of the problem and we will be an important part of the solution.

I would prefer that Senator Byrd's resolution recognize that the nations of the developing world will need some extra time, perhaps as much as 10 years, to put their binding reductions in place. I am hopeful that a compromise can be worked out to everyone's satisfaction.

However, given a choice between sending U.S. negotiators to Kyoto offering unilateral economic disarmament on this subject, and sending them into final negotiations with a stance that demands world-wide equality of treatment now, must choose to protect the best interests of the United States.

Thank you.

Senator REID. I'd also like to tell the chairman and especially my friend, Secretary Wirth, that I scheduled my time to be here from 10 a.m. to 11:15 a.m. and that time has gone and I will be unable to listen to his testimony. I apologize.

Senator CHAFEE. I know you made the effort and unfortunately we had the intervention with those votes and that's just life in the Senate. We're glad you were able to come even though briefly.

Mr. Secretary, why don't you proceed?

STATEMENT OF TIMOTHY E. WIRTH, UNDER SECRETARY OF STATE FOR GLOBAL AFFAIRS, DEPARTMENT OF STATE

Secretary WIRTH. Thank you very much, Mr. Chairman.

Senator Baucus, Senator Reid, Senator Kempthorne, Senator Inhofe, we appreciate your being here. We also appreciate the great interest of this committee. I read with interest the transcript of the science panel and discussion that you had. Questions were raised earlier and we may have a chance to touch upon them today.

My part of the discussion this morning is to focus on the ongoing negotiations toward the next steps under the United Nations Framework Convention on Climate Change. These negotiations began in August 1995 and are scheduled to end in December at the third conference of the parties in Kyoto when we hope to adopt a new protocol or other legal instrument.

In his address last month to the United Nations General Assembly Special Session, President Clinton noted that, "The science is clear and compelling" and the President committed the United States to strong leadership on climate change.

The President, as well, committed himself to engage the American people and the Congress in a dialog to explain the real and imminent threats from climate change, the economic costs and ben-

efits involved, and the opportunities that American technology an innovation can provide.

The President also committed to "bring to the Kyoto conference a strong American commitment to realistic and binding limits that will significantly reduce our emissions of greenhouse gases."

In recent weeks, interest in the negotiations has intensified, particularly in the Congress. The Administration welcomes this interest, Mr. Chairman, and wants to encourage the broadest possible dialog as we work toward a new agreement in Kyoto and urges the Senate and House leadership to establish observer groups with whom we can work even more closely in the weeks and months ahead.

I would like today to focus on two concerns, first, how the actions negotiated under the Climate Convention correspond to a significant environmental objective and second, the need for developing nations to acknowledge more fully their role in meeting that objective.

I won't repeat the science here this morning. That is familiar to all of you, particularly after your last hearing, but let me just briefly make one comment on effects. Virtually all the studies on the effects of climate disruption have focused on a predicted doubling of atmospheric concentrations of greenhouse gases; but as Senator Baucus pointed out in his opening statement, unless significant actions are taken early in the next century, it is very likely that atmospheric concentrations will, by the year 2100, nearly triple the pre-industrial level and rise higher than at any point in the last 50 million years.

Changes to our climate system would also continue beyond the effects the current studies predict. The risks would increase dramatically as concentrations continue to rise. Moreover, there is no reason to believe that these additional effects would be linear. They would most likely take unpredictable and highly undesirable paths.

Let me now move on to the division of responsibilities between the developed and the developing countries.

As I noted earlier, we know that man-made emissions have increased the concentration by about 30 percent, from 280 ppm in pre-industrial times to around 366 ppm today. We know that the industrialized countries have put most of the carbon into the atmosphere and that CO_2 lingers there for 100 to 150 years. We know that the United States is the largest emitter of greenhouse gases; we have 4 percent of the world's population and contribute 22 percent of the carbon. We also know that given current trends, the developing world will pass the developed world as an emitter in about 30 years. At that point, the developing world will have about 70 percent of the world's population. China, with it's 1.2 billion people, will probably pass the United States toward the end of the first quarter of that century.

So action by the industrialized nations alone will not put us on the road to safe concentrations of greenhouse gases. We need action by the developing countries as well.

It's very clear from all our discussions and negotiations to date that if the developed countries, with our current economic capacity, technical capability and energy-intensive lifestyle, don't go first, setting the example and reducing emissions, then developing coun-

tries will not act either. We must lead the way and we must move soon.

If not, a doubling of concentrations becomes certain and we put ourselves on the road to a tripling or even higher levels of concentrations, the consequences of which are uncertain but likely to be catastrophic.

The United States has put forward a number of proposals which are outlined in my testimony and the attachments. Perhaps most controversial is Article 16, our proposal which calls for developing country parties to adopt by the year 2005, binding provisions so that all parties have quantitative greenhouse gas emission obligations and so that there is a mechanism or trigger for automatic application of those obligations based on agreed criteria.

In urging this policy of what we call evolution, the United States is far out in front of almost all other countries and we're being criticized accordingly. For example, several developed countries believe that our proposal imposes unfair burdens on developing countries. Most countries in the developing world believe that evolution goes beyond the scope of the Climate Convention and the Berlin Mandate. We think we have the concept about right. No one should be exempt. We emit the most, so we have to act first, but others have to phase in over time.

The overall negotiation on climate change is extremely complex, the most complex I've seen in 25 years of public life. The evolution aspect is perhaps the most important of all. We have put forward some proposals, some in Congress have as well. Now we have to hammer out a final proposal and negotiating position. We welcome your input, support and creativity as we work to solve this problem and I look forward to hearing your ideas, questions and comments today.

The issue is not whether developing countries, especially the big and rapidly developing ones, take on quantified commitments to limit or reduce their emissions of greenhouse gases. Clearly, it will be impossible to abate the threat of climate change unless they do. The issue is when such commitment should begin and what criteria should be used to establish them and to whom they would apply.

The Framework Convention, which President Bush signed and to which the Senate overwhelmingly gave its approval, established the principle that with respect to climate change, the world's nations have common but differentiated responsibilities and varying capabilities. Insisting the developing nations immediately accept binding emissions targets that industrialized nations are seeking to negotiate is neither realistic, nor consistent with the Convention approved by the Senate, but insisting that those developing nations now responsible for a growing share of global greenhouse gas emissions should have no further obligations to act until they cross some threshold of national income or emissions per capita, is equally unrealistic and inconsistent with the Convention's ultimate objective.

The agreement reached in Kyoto will not solve the problem of global climate change. No matter how ambitious, it will represent only a second step along the much longer path toward achieving the Climate Convention's ultimate objective. As we prepare for Kyoto, we must also prepare for further steps beyond it. In particu-

lar, we must ensure that all nations responsible for a significant share of current global greenhouse gas emissions accept the need to limit or reduce their emissions and that they begin to move in that direction.

What a Kyoto agreement can do is provide nations with the tools they will need to achieve a significant, binding greenhouse gas limitation and reduction commitment. These tools include greenhouse gas emission budgets over multiyear periods that will help smooth out annual fluctuations. They include full national flexibility in the choice of policies and measures to meet such binding emission budgets. They include emissions trading among nations with binding emission budgets, with the participation of the private sector in the trading regime which we believe will help significantly lower the cost of compliance. They include joint implementation for credit between nations with binding emissions budgets and those that do not yet have such budgets both to lower the cost of compliance and to promote economic development and environmental protection.

Mr. Chairman, we have charted an ambitious course for the months ahead. The tremendous risk to our plant demand nothing less. With your continued support and the support of other Members of Congress, I am confident that we will obtain an outcome in Kyoto that will represent a significant step forward on the much longer path toward safeguarding the Earth's climate system for present and future generations.

If I might, I'd like to have my statement included in full in the record and we look forward to answering any questions that the committee might have.

Thank you, Mr. Chairman.

Senator CHAFEE. Thank you very much.

What we will do is have a round of questions. I would say each member will have 6 minutes and we will go around and come back so that everybody gets a chance.

You say in your opening statement, President Clinton noted "The science is clear and compelling." I didn't get that feeling. Could you summarize the science that is clear and compelling?

Secretary WIRTH. As you know, this is probably the most peer-reviewed, carefully studied international issue that mankind has looked at. The international community established the Intergovernmental Panel on Climate Change in the 1980's. That made its first report when you and I were at the Rio Conference just before the 1992 Rio Summit. It's second report was completed in the fall of 1995 and was published in the spring of 1996.

The consensus of that study—of almost every climate scientist in the world—was that man's impact on the climate can now be seen. That was Volume 1.

Volume 2 pointed out what some of the impacts of this are going to be. As Senator Kempthorne pointed out, there's a lot of uncertainty as to exactly where, how much, how fast, and a great deal of work to be done, but Volume 2 began to tease out what some of the implications of this were.

Volume 3 contained work by a great number of economists as well as people in the climate world as to what steps ought to be taken. It's a very impressive piece of work.

It was our judgment, in summary, looking at the science as it comes to us it was important and prudent for us to establish steps now to begin to take what many have called an insurance policy.

There are still uncertainties, Senator Kempthorne, as to exactly where, how much, how fast, and that is well recognized, but the overall trend, in our opinion, is so compelling that we believe we have to begin now to take steps. As Senator Baucus pointed out, the earlier we take steps, the easier it's going to be to make these kinds of changes, the less disruption we'll have, the fewer costs we will incur. We have to begin to make those steps now, in the form of the insurance policy described in our proposals for Kyoto.

Senator CHAFEE. The big stumbling block probably will be the developing countries and in your testimony, you indicated it's very, very important to get them aboard. I think it is important for us to recognize.

I believe from your testimony, you say we've got 4 percent of the population and emit 22 percent of the CO_2 and those are startling statistics and statistics that the developing countries know as well as we do.

When you seek the participation of the developing countries, which means I would gather that they are going to accept some legally binding emission reduction targets, how are you going to do that in a timely manner?

Secretary WIRTH. As I pointed out in my testimony, we have a five-part approach for bringing the developing countries on board. In summary, let me say that Senator Byrd had a very appropriate metaphor for this, which I think is very helpful. That is, we're all in the same boat together. This is a problem that we all have to face and it's a very significant one. In that boat, we begin with a bigger oar than the developing countries but over a period of time, the size of their oar phases in so that when we get to say 2030, 2040, we're all pulling together oars the same size. That's not a bad metaphor to understand the process of phasing in.

We have proposed a phase-in approach far beyond what almost anybody else in the world has done. The developing countries are required to advance their existing commitments on issues like energy efficiency, elimination of subsidies, privatization of energy, and the investment in renewable energy resources. There are a whole series of things that we want them to be pinned down to in advance.

Second, we would like to create what is called an Annex B. As you know, Mr. Chairman, the Framework Convention has Annex I countries and non-Annex I countries. The Annex I countries are the developed countries and then there is everybody else. There are a number of countries who, over a relatively short period of time, are now graduating toward developed country status. We think as they graduate, for example, as they assume membership in the OECD, they also have to assume certain obligations, so we are proposing a second sort of interim category.

Third, we're calling on developing country parties to adopt by 2005, binding provisions so that all parties have quantitative emission obligations.

Fourth, we have very important joint implementation processes which we think add real incentives to bring the developing countries on board. It's in their advantage to do so.

Finally, we're carrying out other bilateral initiatives as part of our treaty obligations to promote energy efficiency, forest protection and various technical country assessments.

This is the trickiest and most difficult issue in the whole negotiation as you pointed out in your resolution, Mr. Chairman. We appreciate your help and work on that and look forward to working with you and other members of the Senate.

Senator CHAFEE. Many of us look back on the Montreal Protocol and the CFCs and what we did there, but when you look at that, it seems easy compared to this problem.

As you recall, we had binding limitations in that by the year 2005, whatever it was, I can't remember the exact dates, the production of a certain type of CFC had to be completely banned. So we were able to achieve that, plus we had wonderful cooperation from American industry on it.

I see my time is up. I'm going to give everybody else 8 minutes and I'll take two more myself and then everybody will have eight.

Dr. Yellen, in the beginning of your testimony, you said, "The Administration has not settled on a particular set of new policies to reduce greenhouse gas emissions." Kyoto is 20 weeks away. That is not very far, so if you haven't settled on it, you'd better hurry.

[Laughter.]

Senator CHAFEE. What is your answer?

Ms. YELLEN. I should perhaps clarify and say there are some elements as the Under Secretary has mentioned of the United States approach that certainly are settled on. These have to do with the joint implementation, international emissions and other flexibility provisions that I think are very important.

With respect to targets and timetables, that isn't settled and what that would entail in terms of domestic implementation.

The President has indicated that he really thinks it is important before we settle on a policy to have a period in which he and the rest of the Administration become personally heavily engaged in hearing from broadly, Members of Congress, elected officials, business and labor leaders, and others that are interested, about their views on this topic. We would like to get that kind of input before trying to settle on the a policy.

Senator CHAFEE. On page 10 of the testimony you submitted to us, you said, "What a Kyoto agreement can do is provide nations with the tools they will need to achieve significant binding greenhouse gas limitation and reduction commitments."

Are you saying there will be binding greenhouse gas limitations? Is that what your thought is?

Secretary WIRTH. Yes. It's our belief that we have to go to a binding approach on this sort of thing.

Just as a quick aside, I might say that Geneva was not a negotiation where we were making commitments; we were rather proposing what ought to be done and that might be the explanation.

We believe that the non-binding aim that was built into the initial Framework Convention coming out of Rio has not been adequate to the task. We're going to miss it, everybody else is going

to miss it except the United Kingdom which made a transition to natural gas, which was very painful and difficult for them to do and very laudable. They did that for a lot of other reasons, for the most part. Germany will make it because they adopted utilities in East Germany and shut them down which was difficult for them to do.

Nobody else in the world is going to make the non-binding aim of Rio. We believe that we need a binding agreement that all nations really step up to, and really understand what they're committing themselves to, to make very significant progress.

A binding agreement gets us beyond rhetorical flourishes into a kind of serious reality.

Senator CHAFEE. I agree you've got to have a binding agreement if you're ever going to get the thing done.

My times is up. Senator Baucus.

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

Mr. Secretary, as you know, any treaty adopted by the Senate requires two-thirds of the members of the Senate to vote for a treaty. As you also know, Senator Byrd is sponsoring a resolution which basically states that no treaty should be adopted unless the developing countries are equally committed. He has two-thirds of the members of the Senate as co-sponsors of that resolution, and he's intending to push that resolution quite quickly I would expect before Kyoto.

What is the Administration doing to turn that vote around? It seems to me that the Administration has quite a difficult job ahead of it because there is quite a feeling in the Senate that yes, the United States must do something about greenhouse gases. I think most of the Senators think that, although there are some who do not think that, but certainly those who feel the United States should not act, feel if we act that certainly all countries should, in an appropriate way, be a part of this solution. After all, we're all on this globe together.

India and China together should I think be close to 40 percent of greenhouse gas emissions.

We all know the facts and the figures and we're all trying to find a solution here, but my question really is, what is the Administration's plan or what is the Administration going to do to persuade the Senators, by a two- thirds majority, that we ought to adopt a treaty?

My advice to you is that we have to go farther than the United States does in persuading not only developing countries, but also the other developed countries that the developing countries have to step up a little more than they have thus far?

Secretary WIRTH. We recognize the size of the challenge that you lay out in your question. Let me just take pieces of it if I might.

First of all, the engagement and leadership of Senator Byrd, we applaud. I have met with Senator Byrd. I don't know how many of you have had the opportunity to sit down and talk with him, I suppose all 70 who signed on.

Senator BAUCUS. And some who have not signed have spoke with him.

Secretary WIRTH. And some who have not signed on.

Senator Byrd's resolution, in our opinion, is largely on the button and comes very close to the Chafee Resolution which we also very much applaud and support.

The Byrd Resolution related to sharing of economics and engagement of that one element of it. We thoroughly agree with that. Second, we thoroughly agree with the engagement of a Senate observer group in the process. Third, we very much agree with the thrust of what he's saying related to developing country commitments.

Exactly how those get defined is the thrust of our proposals for Kyoto which I outlined, the five-point position that we're taking.

China and India together are enormous producers of greenhouse gases and are going to be at the same time a huge market over the next 30 years. It is estimated that China and India together will be building 1,500 megawatt plants in the next 30 years. That is the equivalent of 50 percent of the installed energy capacity in North America. That's a remarkable opportunity for us.

Senator BAUCUS. That's why many have signed onto the Byrd Resolution.

Secretary WIRTH. We have to engage them both to get them to recognize the imperative of them dealing with the problem. China, as was pointed out in some of the earlier comments—I believe yours, Senator Inhofe—has got major problems of their own. They are starting to recognize those, they are starting to move in this right direction.

We are negotiating as well with the Indians. We have to get them to understand that it's in their interest. Joint implementation, emission trading and other market mechanisms can be helpful to them as they move along the course of economic development.

Senator BAUCUS. As I understand it, the 2005 commitment for developing countries—I don't want to put words in your mouth—is essentially a proposed commitment by that date, talk. That is, it is not a commitment to by that date, commit to certain specific targets?

Secretary WIRTH. Under the 1992 Climate Treaty, there are certain existing commitments which the developing world is required to undertake. We believe those ought to be more broadly articulated, that those ought to be more carefully defined. These existing commitments can be very significant if they meet them. They are already required to do that.

We think that specificity in their requirements ought to be part of the agreement that we reach. That's part of the phase-in policy. It won't be the same targets and timetables that we have now, but it's moving them into that over a period of time.

Senator BAUCUS. Can you describe the Annex B you talked about? What is that about?

Secretary WIRTH. The idea of an Annex B is that there are certain countries that are developing very rapidly which have assumed, for example, OECD status. They get that status, that privilege of membership, but coming with that are obligations. We believe there ought to be a sort of new interim category into which countries move with different responsibilities in the Climate Treaty.

Senator BAUCUS. Why not follow that step a little further and have not only Annex 1 but Annex B, C, D and E and all countries commit but at different rates?

Secretary WIRTH. That's generally the idea, that there will be different rates.

Senator BAUCUS. But the point is they all commit to certain targets?

Secretary WIRTH. We would like to see that kind of commitment from all countries. We're dealing with 150-some signatories of the Climate Treaty, but we're really talking about maybe 35 countries that make major contributions. If we could get those 35 under the tent, as suggested by Senator Kempthorne's questions, we would have made an enormous difference.

Senator BAUCUS. Am I correct in assuming that some other developed countries are not as interested as the United States?

Secretary WIRTH. That's true. We're far out front.

Senator BAUCUS. Why is that? Why would the European Unions not be as interested, including developing countries as quickly as the United States?

Secretary WIRTH. I don't want to get into the politics of what may go on in Germany or wherever. I think they are a little skeptical of our engagement in that because we haven't put up numbers yet. I think some of that is their way of saying to us, "why haven't you put up your targets and timetables yet, we're not going to agree with what you're saying until you come forward with your targets and timetables."

We'll do so later this fall and then I think it will be easier for us to bring them on board.

There are also some suggestions that they don't want to get far out front in placing demands on the developing world, that maybe they can gain some economic advantage by having us out front as being the guy really pushing on the developing countries and they come back and say, we're the good guys.

Senator BAUCUS. If you had to guess, what's the main reason?

Secretary WIRTH. The main reason is that we haven't yet put out our targets and timetables, so they're not going to pick up our proposals until we put out clear indications of what we believe we're going to do.

Senator BAUCUS. So you think if we do put out our targets and timetables, then they too will then come in and suggest that developing countries step up more quickly?

Secretary WIRTH. Yes, I believe that's the case. We take the lead, we're the key area in all of this. We do a reasonable targets and timetables approach in Kyoto. We have that on the table mid to late October, that's part of that negotiation; then I think it's much, much more likely that we're going to get our proposals on economic flexibility that Dr. Yellen was outlining and it's much more likely then that they go along with us in pushing for developing country participation.

We have then the opportunity and the Annex 1 countries or the developed countries to begin then to make a much clearer and coherent case to the developing countries to get on board. As the chairman pointed out, getting the developing countries on board is going to be the toughest part of this whole negotiation.

Senator BAUCUS. Thank you.

Senator CHAFEE. Senator Inhofe.

Senator INHOFE. Thank you, Mr. Chairman.

Secretary Wirth, these reductions on fossil fuels that would be required by an agreement, where would they come from? Let me put it this way, would the armed services be coming under this requirement, would they be exempt?

Secretary WIRTH. Our armed services are already making very significant steps toward their own economic efficiencies in the use of fuel, the recycling of materials and so on. We're way out in front of any other armed service in the world on that.

Senator INHOFE. But I'm talking about are they going to be required, as I've seen some of the requirements that are going to be proposed, they would not be exempt in any way, would they?

Secretary WIRTH. I don't think Secretary Cohen would want them to be exempt.

Senator INHOFE. I'm sure he wouldn't, but would you?

Secretary WIRTH. No.

Senator INHOFE. So they would be included also. What about political subdivisions, State and local governments?

Secretary WIRTH. I think part of this process would be that State and local governments, like my city of Denver, the State of Colorado, would make very significant efforts to move toward natural gas vehicles and so on.

I think there is a sense of shared responsibility. Of course they'd be involved.

Senator INHOFE. I'm a former mayor, so I'm a little sensitive to this type of thing. Do you think this would be, in your mind, interpreted as an unfunded mandate?

Secretary WIRTH. An unfunded mandate?

Ms. YELLEN. A requirement to do something.

Senator INHOFE. An unfunded mandate, yes.

Secretary WIRTH. I think most of the things we're proposing are going to be, as the economic studies suggest, steps that are going to end up like an insurance policy but most importantly the guts items are going to pay for themselves, at least for a long period of time.

Senator INHOFE. So you don't see there could be any costs incurred by political subdivisions to comply?

Secretary WIRTH. Over a period of time, I would think the investments made in terms of energy conservation and efficiency during a first phase like this would absolutely pay for themselves.

We then get into a situation as we're looking at steps 20, 30 years down the line in which we're involved in very significant technological investments where we're really changing the nature of the way in which we fuel much of our economy.

Senator INHOFE. But there will be costs incurred by State and local governments, you agree with that, don't you?

Secretary WIRTH. Sure.

Ms. YELLEN. I'd just add that I think what's being proposed here is a national cap on emissions and I think what you're talking about would be particular emissions limits placed on the armed services, on individual cities.

Senator INHOFE. Exactly. They're going to have to be a part of this. They're not exempt.

Ms. YELLEN. We really have not reached a conclusion as to how to go about implementing any overall national emissions target domestically. Certainly one kind of system that one could imagine, that one could think of——

Senator INHOFE. You do not anticipate that the costs incurred by State and local governments would somehow be borne by the Federal Government, or do you?

Ms. YELLEN. I think that until we have discussed what kind of scheme would be used in order to try to meet targets and timetables, it's really impossible to discuss what the costs would be.

Senator INHOFE. We've established there will be some costs—they might be high, they might be low—but there will be costs. My question would be, do you anticipate that the Federal Government will step in or should step in?

Secretary WIRTH. That would then be up to the implementing legislation and what the Congress, in its wisdom, decided to do based upon our consultations with the Congress. As Dr. Yellen has pointed out, we haven't gotten there yet, but it is fair to say that nobody is exempt, a developing country or whoever it may be.

Senator INHOFE. Let me suggest that after you left this body, we did pass legislation on unfunded mandates in terms of political subdivisions. You may want to look into that.

I want to move on here. In my opening statement, Mr. Palmeritz made a statement that "Our goal, Mr. Chairman, is that all parties participate in the next round of negotiations." Let me find it here. "Are we going to agree to the legally binding instrument in Geneva, to a legally binding instrument?" and he said, "No way." You were quoted a few days after that as contradicting that. Who is right?

Secretary WIRTH. Again, as I pointed out earlier, I'd have to look at the context of that, but Geneva was not a negotiating session in which we agreed to some thing and it's part of a negotiation. That is not what Geneva was.

Geneva was a preparatory meeting and at Geneva, we laid out the U.S. proposal and included in the U.S. proposal were legally binding targets.

Senator INHOFE. That answers the question. I want to get to the one I don't understand and I need to have it explained because in your opening statement, which I did not read but I was here during your opening statement.

You made several comments. I think you said it's not realistic to assume that any product that comes out of here is going to impose the same thing on developing nations as developed nations. Is that correct?

Secretary WIRTH. That's true, yes.

Senator INHOFE. And you said it several different ways. This also you said is maybe the most contentious part of this.

Secretary WIRTH. Most difficult, that's right.

Senator INHOFE. Just about 5 minutes ago, this Senate Joint Resolution passed the Senate Foreign Relations Committee and I understand there are only two votes against it. To my understanding, they have somewhere between 66 and 70 co-sponsors. You've addressed this.

As I read it, my interpretation is that if you don't treat them the same, we're not going to ratify them. Is that a different interpretation than you had?

Secretary WIRTH. That is a different interpretation than we have of that. Again, you would have to talk to Senator Byrd and Senator Hagel about their intent on this. As I pointed out, I thought the most useful metaphor in describing this was the boat and the oars. Senator Byrd said we're all in the same boat. We start with a bigger oar, over a period of time the size of their oar phases in.

This is not dissimilar to what we've done in other environmental treaties. I might say Senator Chafee raised the Montreal Protocol. Under the Montreal Protocol, the developing countries were given a longer period of time in which to phase-in and as the Senator pointed out, that has been an extraordinarily successful environmental treaty.

Senator INHOFE. I appreciate that, Mr. Secretary, but I read this and I don't see that this is subject to interpretation or legislative intent. I have talked to both Senator Byrd and Senator Hagel. I'm going to read it. It states very clearly that we're not going to ratify a treaty, an agreement or a protocol which would—I'm directly reading from paragraph A—"mandate new commitments to limit or reduce greenhouse gas emissions for the Annex 1 parties unless the protocol or other agreement also mandates new specific scheduled commitments to limit or reduce greenhouse gas emissions for developing country parties within the same compliance period." What is ambiguous about that?

Secretary WIRTH. We agree with that, unless the protocol or other agreement also mandates specific scheduled commitments. We're agreeing with that. That is in our proposal. It does not say the same commitments.

If one followed your interpretation, Senator, as I understand what you're suggesting, any new commitments under line 1, mandate new commitments, that would then go to the end of that sentence that those would be the same new commitments. Nowhere in the Byrd Resolution does it say the same new commitments for developing parties. That is not Senator Byrd's intent.

Senator Byrd's intent is to start with a commitment which is lower for the developing countries and phase that in to what the developed countries do.

Senator INHOFE. Respectfully, Mr. Secretary—and my time is up—I have to tell you I read this, it's in the record and it says the same. It doesn't use the word "same;" it says, you shall not expect anything from developed countries that you don't also get from developing countries.

The reason I'm concerned about this is that you're going into negotiations knowing in advance that if you don't treat them both the same, you're not going to get ratification. You don't agree with that?

Secretary WIRTH. Senator, the word "same" in here applies to the compliance period, not to the requirements. The word "same" is used as a way of defining compliance periods, not requirements. That's what the Byrd Resolution says, will be in the same compliance period but not the same requirements within that compliance period.

They will start with lower requirements in that same compliance period. Over a period of time, those lower requirements become greater and we all have the same size oar over a period of time.

Senator INHOFE. Thank you, Mr. Secretary. I don't know how to word it any other way.

Senator CHAFEE. Senator Kempthorne.

Senator KEMPTHORNE. Mr. Secretary, in your statement, you said industrial nations like the United States have to go first in reducing greenhouse gas emissions because the developing countries won't act on their own.

You also stated that developing countries will emit more greenhouse gases than industrial nations within the next 30 years.

Under the Administration's approach, wouldn't industrial nations be required to reduce their emissions and limit economic activity while developing countries would be allowed to continue to increase their emissions?

Secretary WIRTH. Yes, that will be one of the results in this first period of time. We will be limiting our emissions. We hope that we will get to a point of stabilization at a particular time and that all developed countries will.

And soon thereafter, when the developing countries begin to phase in their own requirements and steps, then we all end up with the same kinds of requirements.

Senator KEMPTHORNE. Are we, to follow your metaphor, going to be retarding or holding constant the size of our oar, while the other countries will be able to continue to grow their oar?

Secretary WIRTH. The oar metaphor relates to the actions that each of us takes. This gets a little stretched, Senator Kempthorne. The oar relates to the power that we put behind ultimately reaching the goal of stabilizing the concentrations of greenhouse gases.

The goal in all of this is that all of us together, sometime in the 21st century, will stabilize the concentrations of greenhouse gases in the atmosphere. The developed countries have been the ones responsible for increasing the level of concentrations, for the most part, from the historic level of around 260 to above 360 today.

We have to say we were responsible, we'll take the first step. We have the technology but you guys are coming along fast and you've got to phase in, not dissimilar from the very successful kind of phase-in approach that we did in the Montreal Protocol.

Would these be legally binding on developing countries?

Secretary WIRTH. Yes. We believe they should be and that's the list of specific items that we have put out there in terms of the enhancement or articulation of their existing commitments.

Senator KEMPTHORNE. How would we enforce that?

Secretary WIRTH. In most international treaties, we have a whole section, and I'll be happy to put that in the record if I might, as to how one goes about reporting and meeting requirements and compliance. That's not in my testimony but I'll submit that to the record.

We have proposed a whole package of approaches ranging from reporting to public disclosure of this to expert understanding and expert analysis of what goes on. For the most part, Senator Kempthorne, when you get to a legally binding treaty like this, if a country goes through the process of examining what it has to do

and makes these commitments, then they're going to meet those commitments. Nations, for the most part, do what they say they're going to do.

Senator KEMPTHORNE. I wish we had more time because I'd really like to pursue that. At another date, we will.

Secretary WIRTH. Let's do that. I'd be happy to get together with you, Senator, at any time.

Senator KEMPTHORNE. Dr. Yellen, you stated the effort to model economic impacts based on alternative emission reduction strategies was abandoned, correct?

Ms. YELLEN. The search for a single model or a small set of models. In the case of the IAT report, three were used. The IAT analysis would produce forecasts that we could rely on or regard as definitive. That search was abandoned, but I don't mean to say that we don't expect to use a broad set of tools including those models, and other models that are better at understanding some other issues and many sorts of economic analysis in defending any proposal we would put forward.

Senator KEMPTHORNE. You also State in your testimony, in short, "If anybody tells you that he or she has the definitive answer as to the costs and benefits of particular climate change policies, I would suggest your raise your collective eyebrows."

How are you going to agree to different reduction strategies if you can't estimate the impact of those strategies on the U.S. economy?

Ms. YELLEN. I believe I used the word definitive and to have a single forecast of, for example, the amount of jobs to be gained or lost in a particular industry in the year 2030. That is a search I think we've abandoned and shouldn't try to give you.

Certainly we need to produce economic analysis of any proposal with respect to targets and timetables that the Administration would put forward and try to estimate even if it's only a range of potential impacts, what we think the impact would be on the American economy.

We will, when there is a policy, certainly be prepared to do that.

Senator KEMPTHORNE. As we listen to this testimony, we take it in light of what was discussed at last week's hearing, the raised eyebrows, the abandonment of certain strategies, the data that doesn't quite give us any conclusion.

You also stated, "If we do it dumb, it could cost a lot. If we do it smart, it could result in net benefits." You seem to be telling us to trust the Administration to implement any new requirements reasonably. How can we depend on the Administration to do that when it seems that it cannot estimate the relative costs of alternative strategies to reduce greenhouse gases?

Ms. YELLEN. The Administration has been engaged, for some time now, in attempting to study and understand the potential impact on the economy of an emissions reduction strategy.

While I used the term abandoned with respect to an attempt to produce definitive forecasts of impacts, I certainly do not mean to suggest that we have not learned a great deal from that exercise about what makes a policy sensible as opposed to costly and certainly reading a broader range of economic analysis by economists

outside the Administration, putting it together with what we have done internally, points to some clear conclusions.

One of the things I think the report that we've submitted to you does very well is to provide a general sense of what the gains are when one uses what I've described as flexible or smart strategies.

One of the strengths of the U.S. proposal, I believe, is that it has emphasis on flexible, market-based, smart strategies that provide flexibility with respect to emission reductions when it comes to where they will take place and when they will take place.

Within our own economy, coming back to Senator Inhofe's earlier question, I think the framework that you had in mind earlier was that you would imagine individual firms or State and local governments potentially having clear mandates as to how much emission reduction might be done.

We've not settled on policies but flexible could mean, for example, tradeable permits where if one entity found it very difficult or costly to reduce emissions, they wouldn't have to do it, they could buy a permit to allow greater emissions.

Senator KEMPTHORNE. I appreciate that. I want to slide in one more question before that red light comes on.

Mr. Secretary, the developing countries have a much greater population and are sure to pass, as you pointed out, the industrial nations in greenhouse gas emissions in the next quarter century. Given those facts, why is the Administration arguing in support of a per capita limit on greenhouse gas emissions rather than a proportionate share based on economic productivity? Aren't we really arguing against our own best interests?

Secretary WIRTH. We've not argued anywhere there should be a per capita limit. That would be a very, very unwise policy. If we say we're going to have a per capita limit, that would mean the United States would have the same per capita limitations as India whose population is growing perhaps even faster than their production of greenhouse forcing gases. That would certainly not be a prudent thing for us to do.

Senator KEMPTHORNE. I appreciate that.

Secretary WIRTH. If I might comment on one piece about this model. I'm not an economist. I view with some skepticism all of the modeling based upon a lot of experience on these kinds of issues.

I remember when Senator Baucus and I were freshmen Members of Congress. The Arab oil boycott had first occurred and the economic modelers came in front of the Congress and told us that the cost of oil was going to be $110 a barrel and there would be huge stacks of what were called petrodollars in the Middle East and this was going to be a disaster for our economy. Well, none of those things proved to be the case. The modelers were wrong.

When we did the Clean Air Act, you remember, Senator Chafee, the original model suggested that the reduction of a ton of sulfur would cost about $2,000. We figured out the right kind of a tradeable permit system in the United States and most recently, the cost of that has dropped to $100. The modelers were off by a factor of 20.

They are useful tools to help you begin to think about this but, in summary, what I think we're saying is there is no single model

that is going to give you every dot as to what is going to happen 10 years, 20 years or 30 years out.

Senator KEMPTHORNE. I raise my eyebrow.

[Laughter.]

Senator CHAFEE. We've been challenged by your statement to raise our collective eyebrows, Doctor. I'm not sure we do anything collectively around here.

We will do 5 minutes in this round because we have another panel and I want to make a sure they get a chance.

In the other areas we've worked on that are similar to this, namely you mentioned the Clean Air Act. At that time, you remember the whole acid rain problem was there and many of us took trips abroad and saw what the acid rain had done to the trees in the Black Forest of Germany or Switzerland.

When we came to the CFCs, there was a real concern because there is a direct relationship between the destruction of the ozone layer and the increase in skin cancer. So we could sound the alarm, as it were. I find what is lacking here is the sounding of an alarm.

In your statement, you state, "Based on these warming trends, sea level is projected to raise an additional 1.5 feet by the year 2100," and 2100 is only 100 years from now. "This would, without adoptive measures, flood 9,000 square miles of coastal areas in the United States, notably in Florida and Louisiana and put about 100 million people worldwide at risk each year from storm surges." That is an alarming statistic.

I think the Administration, as I see it, is very, very cautious about going public with statements like that. I think your case is helped by pointing out the dangers that lie ahead if we do nothing.

One of our scientists, Dr. Benjamin Santa, gave a very compelling statement, "Although we will never have complete certainty about the exact size of the past, present or future human effect on climate, we do know beyond any reasonable doubt, that the burning of fossil fuels has modified the chemical composition of the atmosphere.

"The question is not whether but to what extent such changes in atmospheric composition have already influenced the climate of the past century and will continue to influence the climate of the 21st century."

I believe in that and my question to you is, isn't it possible for the President or those who have a bully pulpit to get out there and State what you have stated in your statement to us here?

Secretary WIRTH. I share your frustration about getting the story out and telling the story. The President has really picked up this cudgel. He began very aggressively with a terrific speech at the United Nations 2 weeks ago. I would ask that speech be placed in full in the record.

He has two strong paragraphs in there for making the case. He has made it very clear that he's going to devote a great deal of attention this summer, identifying why this is as problem, pointing out to the American people that we have to move on this, culminating in a White House conference in late September-early October to bring together as much of this evidence as we can.

The President was much taken, for example, by the World Wildlife Fund, which pointed out that in Glacier National Park, 70 per-

cent of the glaciers have melted. The evidence on glaciers around the world, the man that was found in the Alps, why was that man 15,000 years old or whatever, suddenly discovered? The big glaciers had melted.

The young woman who was sacrificed and put into an ice cave in the Andes a long time ago, suddenly found. Why was that? The glaciers are retreating.

Look at south Florida and look at what insurance companies are starting to do there in terms of saying maybe we don't want to ensure here because the incidence of hurricanes may well be going up because there is greater warmth in the water, greater energy there, greater violence in these storms.

These are the kinds of stories and anecdotes that have got to be put together so that people really understand what it's going to mean to them day in and day out. The President has dedicated himself to doing that.

Senator CHAFEE. I know it's easy for us to sit here and say go to it, but I do have the feeling that the concerns haven't gotten out there. That was what made us move successfully in these past efforts I just mentioned, in which you were deeply involved at the time.

I would encourage you and others who have a standing in these areas and we have responsibilities likewise. It isn't just all the Administration but I would urge the President to speak out on these subjects.

I was not aware of this White House conference. That sounds like a good idea.

Senator Baucus.

Senator BAUCUS. Thank you very much. I've been around once.

Senator WYDEN. It's a pleasure to have Secretary Wirth and Dr. Yellen here. I just have a couple of questions for the two of you.

I'm from I think the only State in the United States that has put in place carbon dioxide controls. We are convinced that it is possible to do this in a fashion that is good for the environment and also doesn't cause economic meltdown.

I'd like to ask each of you a couple of questions. One, Mr. Wirth, if you could outline what you think are the most cost effective strategies for controlling emissions? My sense is this would give us a chance to compare some of the alternatives that are relevant here as Congress goes forward on this issue.

Secretary WIRTH. First of all, thank you, Mr. Wyden, for your kind opening comments and we appreciate not only your progressive State, but it's progressive representation.

We do not have, as Dr. Yellen pointed out, a specific proposal at this point, so any comments that I might make are not in the context of a specific Administration proposal.

Having said that, it's very clear there are very significant efficiencies over a relatively short period of time that can be had in our economy. We all worked on those together on the Commerce Committee in the House of Representatives. What was true then is true today.

The Japanese, for example, are about twice as fuel efficient as we are, with an economy that is about close to being two-thirds of

our size. Those are rough numbers. There are great significant efficiencies.

Second, there are real opportunities for us to create very, very productive partnerships with large parts of American industry. You might have seen the piece this morning in the Washington Post by the chairman or president of Chrysler talking about the partnership for a new generation of vehicles. That's the kind of thing we think we can embark upon.

There are real opportunities. We look at deregulation in the utility world. Think about the factor in the climate issue which can be very helpful in coming to the right kinds of economic decisions there. Getting the prices right is, of course, a very important one, to remove subsidies from key areas.

These are some of the items that we can do over a relatively short period of time that can have a significant impact. The automobile example is a longer term one but again, the kind of promising steps that we might make.

A final note, and I would ask Dr. Yellen to comment, this problem is not going to be solved, as you know, by these kinds of short-term measures. This is a long-term pull over 40, 50, or 60 years. The long-term solution is going to come from major technological improvements, changes and innovations. That is where the payoff is going to be.

The sooner we start to get the framework right for developing those long-term technological solutions, the better chance we have of meeting our obligations to our children, grandchildren and great grandchildren.

Senator WYDEN. Is it your sense that energy efficiency, we've seen appraisals that would be in the vicinity of $2 a ton plus tree planting and forest management strategies where modest costs per ton would be sensible kinds of approaches that we ought to look to first.

Secretary WIRTH. We've already embarked upon a number of joint implementation projects with some 17 or 20 of those around the world today. We'd be happy to send you a list of those. Many of those do relate to forestry practices and very progressive forestry practices.

The sequestration of carbon is a very, very important part of anything that we might want to do. Again, here is a good example of where the opportunities for us to develop partnerships with the agricultural community, with the forest product community, are very significant. There's a lot of carbon stored out there in sound agricultural practices.

Senator WYDEN. I appreciate your saying that because there is no question in our minds that looking at sensible forest management strategies is the winner all around. You're going to get more and higher value. Wood products are going to get better habit for species, water quality and as you said, it's a cost-effective way to sequester carbon.

Given that, can the Administration make a special push to ensure that forest management and reforestation programs are a significant component of a global climate treaty?

Secretary WIRTH. We have made that point over and over again and I would commit that to you here, that the commitment and en-

gagement of the forest product industry, agriculture overall, is very important.

I've met with our former colleague, Hinson Moore, who understands this and is a very, very effective spokesperson for his industry. We've met and will continue to do so on this very important issue.

Senator WYDEN. Let me turn to your colleague for a moment.

Dr. Yellen, I'm interested in your thoughts about how a region's economy absorbs the impact of some of these kinds of changes as it relates to carbon dioxide emissions and in particular, what we found in Oregon is that if one does nothing else, nothing else other than look at a market-based kind of system for dealing with these issues, and making a number of the key ones prospective, such as the changes in the power plant area, that alone constitutes a significant effort to deal with this issue in a way that can be absorbed from an economic standpoint. Do you agree?

Ms. YELLEN. I would agree with your assessment. I think that there are a variety of market-based approaches that we could potentially use. Again, I want to emphasize that we haven't developed policies in this area but we've had experience in the United States. It's been very positive with emissions trading of permits in the case of sulfur dioxide and water trading.

We've had some experience in California and other places and I think market-based systems really have the power to work to greatly reduce the costs. They provide flexibility over time with banking and borrowing of permits and across places. You give incentives to firms or individuals who see an opportunity there to make money when they can really reduce emissions very effectively, very cheaply. They have now an incentive to do more than they would otherwise be required to do because they can profit from it and reduce the cost to others that would find it costly.

Senator WYDEN. I came in late.

Senator CHAFEE. You did come in late and the red light is on. What we'd like to do is go to Senator Baucus.

We have another panel, I want to remind members of that and we want to give them a fair shot, plus we want to have an opportunity to ask questions. So I would like to move along here.

Senator Baucus. We'll get back to you, Senator Wyden, if you wish some more on this.

Senator BAUCUS. Secretary Wirth, one of the questions here obviously is how we implement controls. You talked about market-based mechanisms.

The first question I have, the degree with which we think the emissions trading system which has worked under the Clean Air Act, in sulfur in particular, was transferable to greenhouse gases on a global level.

Ms. YELLEN. My sense is, although we've not concluded a study of that, an emissions trading system could be developed that would work for carbon dioxide emissions if we wanted to go in that direction.

That is why there are proposals here for international trading.

Senator BAUCUS. Why is it that the Europeans are resistant to that idea? I asked Secretary Wirth that question. I understand the

Europeans are resistant to the kinds of emissions trading proposals for carbon dioxide that we have adopted for sulfur dioxide.

Secretary WIRTH. The Europeans have their own emissions trading system in their proposal. I think disingenuous is too tough a word but they are saying to us we don't want to have emissions trading but the whole proposal made by the EU is premised upon a bubble that would include all European countries.

It would allow Portugal, for example, to increase their numbers by 40 percent, while Germany decreases by 15 percent. If that's not emissions trading, I don't know what is. So they're saying you guys can't do it internationally, but we can do it within the EU. We're saying, wait a minute.

Senator BAUCUS. Practically, they do because they practice emissions trading but they will probably agree in a more comprehensive way.

Secretary WIRTH. I think they will when we get there.

Senator BAUCUS. My next question is, you mentioned Mr. Easton's piece in the Washington Post. His main point is to wait until there is better technology on how to deal with all of this.

Are we expending enough effort in this country, not only in cars but in coal-fired technologies, to be more fuel efficient? Could we do a better job there?

Secretary WIRTH. Fuel efficiencies of our energy technologies are greater than any place in the world. Our new technologies, you talk to someone like the Enron people about what we can do and what we're promoting around the world and the dramatic efficiencies from where we are with our best technologies and elsewhere. You're familiar with all of these Senator Baucus.

The automotive industry has told us that they would expect to get very, very significant efficiencies, like 88 miles per gallon.

Senator BAUCUS. This is a "chicken before the egg" question because I think we find efficiencies when we have to very often. For example, the oil shock enabled us to find new efficiencies.

This committee years ago asked the automotive industry to develop the catalytic converter. First of all, they said they couldn't do it. Then they did it and they found out in doing so, they were much more efficient. They developed a much more efficient engine and fuel exhaust system.

Again, sometimes this world is run by deadlines and when you have deadlines sometimes you're more likely to do something than when you're not.

I wish you well. This is a daunting task, but it's a necessary one.

Thank you.

Secretary WIRTH. I might say we believe that the framework that we've laid out over a period of time provides exactly the kinds of incentives and direction that is needed to do just the sort of pressure and push for the next steps that have to be taken.

Senator BAUCUS. Your key problem right now is getting developing countries to commit to specific numbers by certain dates.

Senator CHAFEE. Senator Wyden.

Senator WYDEN. Just one question. To continue this point on the economic impact for a second, Dr. Yellen. I think we've seen in the State of Oregon, for example, how you can go about making some emissions limits in a cost-effective kind of way.

My sense is that to do nothing is going to have extraordinarily bad economic consequences. I gather Secretary Wirth talked about this as something of an insurance policy.

We recently had a conference in the Pacific Northwest where a group of independent scientists predicted climate change could bring a whole host of problems to the region's water resources, forests, agriculture, energy, water shortages, diseases forests, flooding, a variety of these.

Has there been any ballpark estimate given to calculate the economic consequences of doing nothing? I know we have spent a great deal of time thrashing around with these estimates on what happens if you do this and this, particularly from some who are not advocating action at all.

It would seem to me we also ought to try to get a ballpark set of costs for what happens if you do nothing.

Ms. YELLEN. Quantifying the cost of doing nothing with respect to environmental damage, public health and other issues is extremely difficult, very uncertain. Most modelers don't even include the benefits side of addressing climate change in their model. Indeed, in the report we sent to you, you'll see no modeling of the benefit side.

There is some work in the economics literature and I could try to get back to you and give you some of the results from that literature, that have tried in a very rough way to estimate the benefits from exactly what you're talking about and they are significant. I'd be happy to send you some further details.

Senator WYDEN. The kind of example that would concern me is if you mess up your water supply, for example, what we know in the Pacific Northwest is that's going to make it hard to attract high tech companies because one of the things they have said again and again is that they need access to clean, pure water.

It would seem to me that economic models that would address doing nothing and what happens if your water gets fouled and what happens when it has economic consequences for high technology companies is important.

Your calculus now is that this would have major economic consequences but modeling is difficult?

Ms. YELLEN. It's hard to put a price tag on the consequences, but certainly this is why we're talking about it because obviously there are benefits from acting and there would be costs from failing to act.

Senator CHAFEE. All right. Mr. Secretary, looking at the greenhouse gas emission curves, how long do you estimate we can afford environmentally to wait around before getting this participation by not only the developing countries but the developed countries as well?

Secretary WIRTH. It depends on what assumptions you make about what a harmful concentration of greenhouse gases may be. Most of the environmental modeling has been done on a doubling of parts per million of carbon in the atmosphere. We're 30 percent of our way there; we're probably going to get there sometime in the second quarter and before 2040–2050, we're going to get to doubling. That's where the sea level rise and most of those predictions come.

If we don't start to act now to break into that curve, there is no way in the world that we can stop it doubling. We have to start, as Senator Baucus pointed out, now. There are some very sophisticated modeling curves about greenhouse gas emissions and I would like to submit those for the record because they do show where the curve and the breakpoints are.

If we start now, how likely is it that we can stop it doubling. If we wait for 20 years, it's almost impossible that we can stop it doubling and we'll move rapidly to tripling. When you start to get between doubling and tripling, most scientists would agree that the impacts become even more severe and we're probably, as I pointed out, no longer into linear impacts but we're going to see some major surprises along the way.

Senator CHAFEE. That is a good presentation and I hope you are able to sound that alarm publicly to a great extent.

Secretary WIRTH. We appreciate your help in doing so, Senator, and look forward to working with you.

Senator CHAFEE. Thank you very much.

Secretary WIRTH. Thank you.

Senator CHAFEE. We appreciate both you and Dr. Yellen.

Now, Mr. Kevin Kay, executive director, International Climate Change Partnership and Mr. William O'Keefe. Will they both quickly come to the table and we'll get started because we want the opportunity to hear what you have to say.

What we'll do with each of you is if each of you could give your statements in say 7 minutes, then we will have a chance to ask some questions. Your statements obviously will go into the record.

Go to it, Mr. Fay.

STATEMENT OF KEVIN FAY, EXECUTIVE DIRECTOR, INTERNATIONAL CLIMATE CHANGE PARTNERSHIP

Mr. FAY. Thank you, Mr. Chairman, members of the committee.

My name is Kevin Fay. I'm the executive director of the International Climate Change Partnership, a coalition of U.S. industry representatives and associations as well as international associations interested in the policy development process with respect to global climate change. We appreciate the opportunity to be here today.

ICCP was organized in 1991 to provide a forum to address the issue of global climate change and to be a constructive participant in the policy debate. We continue to recognize the climate change issue as an important matter with which government should be concerned. However, it is a very long-term issue and extraordinarily complex in both its underlying science and its entanglement with the very foundations of the global economic structure.

We have recently communicated our views on the key issues in the Kyoto negotiations to the Administration. I'm attaching this correspondence to my testimony and ask that it be included in the record.

Senator CHAFEE. Yes, it will be.

Mr. FAY. We have also communicated to the President on the issue of the Administration's now incomplete economic analysis, expressing our frustration at their lack of communication on the matters of greatest concern to the private sector, namely the potential

economic impacts of a climate change agreement and the current thinking of future implementation scenarios.

In light of the Administration's demurral on the economic analysis, our frustration only grows. In our view, the Administration made progress in its own deliberations and offered a thoughtful policy framework at the second meeting of the parties in 1996 and we have heard about that here today.

This policy outline includes a comprehensive approach, identification of a long-term objective, identification of developing country roles under the treaty, implementation of flexibility through emissions trading, banking and joint implementation, and avoidance of a laundry list of so-called policies and measures.

The U.S. framework also included a call for a binding commitment which the Administration has subsequently defined as an emissions budget period of undetermined length to achieve reductions of an undetermined size.

While most of the attention has been focused on this part of the discussion, we continue to believe that it is not the only key to a successful treaty agreement in Kyoto or after Kyoto.

You will note in both of the letters we attached, we urged the President and the State Department to reiterate to our negotiating partners that the U.S. policy framework enunciated last July is the only framework that can provide a climate change agreement that is both environmentally beneficial and economically feasible.

Our primary concern has been that the result of the negotiations would focus on only one or two of the key issues, some of which we have outlined in our letter, and that the rest would be left until later.

To date, frankly, we have been disappointed in the progress on most of these fronts and we are pessimistic on the ability to achieve them between now and Kyoto. ICCP is not and never has been interested in an agreement at the Kyoto meeting just for the sake of reaching an agreement. This view will not change.

With respect to the economic issues, which I referred to earlier and the impacts of a climate change agreement on the U.S. economy, jobs and the environment, we remain very concerned. It is difficult to address this issue in any effective way given the lack of dialog on these topics and the lack of information being provided by the Administration.

We know that the economic analysis that has been performed by the Administration and others tells us several important things—that there are costs involved in reducing greenhouse gas emissions; that the costs are likely to be reduced if flexibility provisions are incorporated; that you cannot achieve any reasonable goals either environmentally or economically without developing country participation; and the costs are less if you avoid premature capital retirement or turnover and provide industry the opportunity to manage their way into the technological innovation that will be necessary to accomplish whatever long-term goal is established by the parties to the Convention.

We need to know now, however, what analytical process might be pursued in light of the Administration's current view of the difficulty of completing what it has promised for more than a year. In order for there to be an effective treaty, we believe that the par-

ties must first get the treaty structure right. We have a long way to go before that will happen.

In closing, I believe it is useful to look at previous examples for guidance that may provide a better perspective than the intense pre-Kyoto focus.

More than 12 years ago, negotiators were struggling to complete the Vienna Convention for protection of the ozone layer after more than 5 years of negotiation. These negotiations had taken on a bitter tone as parties, including the United States and the European Union tried to——

Senator CHAFEE. When you say these negotiations, you mean the ozone layer, the Vienna ones?

Mr. FAY. Yes. The United States and European Union tried to push for adoption of their own preferred policy approach to dealing with those depleting compounds. Instead, the parties agreed to that convention without the regulatory protocol and also agreed to establish a series of workshops and information-gathering devices to better understand each others' views.

When negotiations resumed, approximately 2 years later, the parties were much better informed and a treaty structure was adopted that has since proven very durable. The Montreal Protocol which was signed in 1987 has proven much more effective than most of us thought possible at the time.

We raise this as an example not because we believe the issues are identical. They are not and climate change is certainly far more complex. We raise it because as we reach this fevered pitch prior to Kyoto, we want to stress that an effective framework is what counts, not an expedient framework.

The climate treaty needs to be durable for the next 100 years. Our companies have determined that the current State of scientific understanding requires a prudent, long-term approach to address this issue. This view is equally applicable to the climate negotiations themselves.

We appreciate the opportunity to be here today.

Senator CHAFEE. Thank you very much, Mr. Fay.

Now, Mr. O'Keefe, chairman, Global Climate Coalition here in Washington.

STATEMENT OF WILLIAM O'KEEFE, CHAIRMAN, GLOBAL CLIMATE COALITION

Mr. O'KEEFE. Thank you, Mr. Chairman.

Mr. Chairman, members of the committee, I am William O'Keefe, chairman of the Global Climate Coalition. Our members form the backbone of the U.S. economy and encompass companies from manufacturing, agriculture, transportation, energy utilities and mining.

The GCC commends this committee for holding these hearings to discuss the scientific and economic realities of climate change and the implications of the Administration's negotiating strategy in a rational, logical, and open forum.

Recent Senate hearings have put a much needed spotlight on the compelling scientific uncertainties that should permeate every climate change policy discussion. A May 16 article in the respected journal, Science, demonstrated convincingly that based on our current State of knowledge, we do not face an imminent crisis and so

do not need to undertake precipitous actions that could badly damage our economy.

As scientific knowledge about climate change has improved, estimates of future temperature and sea level increases have moderated. In 1990, the Intergovernmental Panel on Climate Change estimated that the average global temperature would rise 4 degrees Celsius by 2100. In 1995, the IPCC reduced that estimate by 50 percent. More recent British and United States estimates reported in Science place it lower than that.

It is ironic that as estimates of the impacts have moderated, the Administration's policy has shifted from support of voluntary programs to legally binding commitments. Although the Administration has not specified for the Senate the critical details of what it might propose, Administration officials have alluded to cutting carbon dioxide emissions back to 1990 levels around 2010 and holding them there.

Such a goal would require more than a 25 percent reduction in projected fossil fuel use. They have not told you, but I will, there is simply no economically viable technology that can replace that amount of energy that quickly. By implication, the Administration may be planning to commit the United States to a severe form of energy rationing. Nor will we escape through allusions to an unproven and unworkable international trading scheme to counterbalance the damage of self-imposed energy rationing.

Other nations have already rejected such schemes. My written statement cites the estimated loss in income, jobs, and U.S. competitiveness that are likely to result from what the Administration has in mind.

MIT economics professor, Richard Schmallensee has stated the matter graphically, "The economic impacts would feel like the energy price hikes of the 1970's with a massive hangover." All of the sacrifice could be tolerated if significant benefits would be secured, but the plain fact is that the Berlin mandate, which is guiding the current round of negotiations, exempts developing countries such as China, India, Mexico, and Brazil, even though they will account for most of the future growth in carbon dioxide emissions in the next century.

Any defensible emissions goal requires participation of all nations. The 2,600 economists who signed a petition on climate change and the 65 Senators who have co-sponsored Senate Resolution 98, and virtually all others who have analyzed this issue emphasize that all countries must participate in any program that is to be beneficial. That program should be guided by the limits of knowledge, anticipate that surprises will occur and recognize the need to adapt as new knowledge is created.

Climate policy is simply not a dichotomy of action versus no action. We agree that action is justified but reject the course being pursued in international negotiations. It is an unjustified rush to judgment.

The major difference between the GCC and our understanding of the Clinton administration is over approach, not need. We believe that a wise policy on climate change is akin to driving in a thick fog. The prudent course of action is to proceed at a speed consistent with how well the car's headlights illuminate the road ahead.

The Administration approach appears akin to driving full speed on the Autobahn on a clear day with no reason for caution. That approach is flawed and risks a fatal crash.

By setting a pace that is consistent with the State of knowledge and economic realities, actions can be taken to achieve any justifiable, long-term goal at one-fifth the cost of the approach being embraced by international negotiators.

We should also invest in information to reduce the uncertainties and to better understand the implications of alternative courses of action.

Finally, we should take steps that will produce benefits under any set of circumstances. The GCC has developed several of these no or low regret actions and have shared them with the Administration. They are based on these points: No. 1, encourage the economic turnover of the capital stock; No. 2, focus investment and research to narrow the range of scientific uncertainties; No. 3, invest in the development of new technologies; No. 4, expedite diffusion of new technologies in developing countries; No. 5, facilitate the investment of U.S. private capital in countries with high emission levels; and finally, No. 6, continue promoting voluntary programs for reducing U.S. emissions.

As we make progress in reducing climate change uncertainties, we can anticipate that additional prudent steps will be revealed. By proceeding at a pace that scientific understanding allows, we can greatly reduce the cost of dealing with potential climate change.

It is a fact of life that precipitous actions driven by current technology and today's knowledge will be vastly more expensive and therefore, less effective than a balanced approach that does not undermine our remarkable record of economic growth and job creation.

Mr. Chairman, that concludes my statement.

Senator CHAFEE. Thank you very much, Mr. O'Keefe.

I'm not sure what you meant in the second of your points there at the end, let me start at the beginning. "The business community has shared these steps with the Administration which are based on these points: encourage an economic turnover of the capital stock." I'm just not sure what that means.

Mr. O'KEEFE. The existing inventory of plant and equipment represents long-lived investments. You should look for impediments to turning those over at the end of their economic life. Depreciation schedules, some provisions in Superfund law, some provisions of the Clean Air Act, new source performance standards and prevention of significant deterioration, all encourage keeping plants in operation longer than would otherwise be justified.

As they are replaced, those that replace them will be more energy efficient. And, anything that will advance, on an economic basis, greater energy efficiency will lead to lower emissions.

Senator CHAFEE. Mr. Fay, it seems to me what you're saying is that the position of your membership is that it accepts the science of climate change. You see a problem there and I guess it was Mr. O'Keefe that talked about the approach that you're concerned with. Was that in your testimony?

Mr. FAY. That's correct, yes, sir.

Senator CHAFEE. But Mr. Fay, as I understand it, you accept that the best scientific information suggests that the human component of climate change isn't small and that human activities already are producing climate change signals that we ought to pay attention to. Am I correct in that?

Mr. FAY. We would agree that the science requires us to pay attention to it, yes.

Senator CHAFEE. What would you do about that? You heard the Secretary's testimony a while ago about what will happen in the middle of the next century, the first part or the middle of the next century, and what do you say to that?

Mr. FAY. We've heard a lot of discussion. You need to cut up the science probably into three different regions of certainty. One is that our greenhouse gases are building up as a result of human activity, yes. There is the scientific consensus concerning temperature.

Senator CHAFEE. What's your answer to the first? Did you say yes, are they building up as a result of human activities?

Mr. FAY. Right, but in terms of the temperature range, we still think the temperature range and the sea level rise projections, there's a wide band there. We agree that the scientific consensus appears to have arrived at that range.

Much beyond that in terms of those other effects you get, whether it's disease spread or agricultural impacts, we think there is an awful lot of uncertainty associated with those, but recognizing that the buildup of the gases themselves, if you realize those effects, would take a long time to retreat from them, it requires you to take a longer term view toward working on that issue.

So we've acknowledged that it's appropriate to begin developing a means to work on this issue.

Senator CHAFEE. Mr. Fay, you mentioned the Montreal Protocol and as you recall, all the signatories had to agree to a phaseout of the use of the ozone-depleting substances. You cited that as something that worked well. What do you think about following that procedure here?

Mr. FAY. Well, I think that in those negotiations, the developing countries accepted the need for them to be participants. I'm afraid I haven't seen that kind of recognition from the developing countries in the current negotiations. There is a continuing insistence on their part with regard to climate change that they have no commitments, despite the fact that the Administration continues to argue they do have existing commitments which we welcome to be elaborated under the existing treaty.

We're very concerned. I think Mr. O'Keefe mentioned the fact that there is virtually unanimous agreement that you can't achieve any reasonable climate change goals if you don't have developing countries participating. You have to find a way to get them on board. I haven't seen where we've achieved the recognition by those countries, however, that they are willing to do that.

Senator CHAFEE. To get them on board, Secretary Wirth stressed we have to go first.

Mr. FAY. I think we already are going first, Senator. We're already implementing the programs voluntarily. It is our technology that is likely to lead us toward solutions on this issue.

What we have asked for is because of the fact a great majority of the investment made by developed countries and developed country industries is going into developing countries, that you have to reach some decision as to what their role is going to be in the treaty process, what their commitments are going to be before we get into any kind of binding period for our own countries and our own companies. That's a minimum of what would be acceptable.

As I said, we're still a long ways away from that recognition by the developing countries that while 80 percent of the emissions may have been associated with our economies over the last 100 years, 80 percent of the emissions over the next 100 years are going to come from their economies.

Senator CHAFEE. Yes, but we've got a situation as we pointed out before where we have I believe the statistic is 4 percent of the world's population and we emit 22 percent of the carbon dioxide.

If I were in China or India and somebody from the west came to me and said, you've got to reduce your CO_2 emissions, I'd say, look, you ought to go first, you keep wrecking the place, not us.

Mr. O'KEEFE. Mr. Chairman, could I comment on that?

Senator CHAFEE. Yes.

Mr. O'KEEFE. It is true that we account for 22 percent of the world's CO_2 emissions, but we also account for at least that much and probably more in terms of the generation of global wealth. CO_2 and other greenhouse gases are not typical pollutant. They are natural elements in nature and increases of CO_2 are the result of economic activity. So when we produce a good and export it to another country, the emission is attributed to us, while a benefit accrues to the importing country.

I think it's much more complex than suggested by a simple statistic.

It may sound good to say that we spoiled the nest or we account for the bulk of the emissions, but we also account for much of the wealth, the food production, the goods and services those countries are using and that ought to be taken into account as well.

Senator CHAFEE. That's a tough one to explain to somebody in India, isn't it?

Mr. O'KEEFE. I don't think anyone is saying that they have to have our technology tomorrow. We ought to do everything we can to aid the growth in their economies because it's the wealthier countries that have the technology that adapt and protect against unforeseen events. So the faster they can grow up the economic curve, the more efficient they will be in using energy. But, they have to participate or else we're not going to make any progress.

Mr. FAY. We have suggested, Senator, as a way of dealing with this through the entry into force requirements for the treaty that while perhaps our efforts may be more aggressive up front, may take place prior to theirs, that you certainly have to have a significant percentage of world greenhouse gas emissions, and that would include India and China, and that you have to have as parties to the treaty, a majority of developed countries, a majority of developing countries, that you try to negotiate a treaty that perhaps as there was in the Protocol, there was a delay in the implementation of the requirements for those countries, but we had them as parties.

What we're not seeing is an indication that they are willing to become parties in that sense. So it's a question of how we assist them in growing smart, not how we stop them from growing, how we get them to adopt the most efficient technologies just as we need to be adopting the most efficient technologies here.

Senator CHAFEE. As I understood the first part of your testimony, Mr. Fay, you were lamenting the fact that there didn't seem to be a dialog with the Administration with your organization and perhaps Mr. O'Keefe's organization. Am I correct in concluding that?

Mr. FAY. We have lots of talks, but it has been pretty barren in terms of specifics, aside from the general framework that they put out where they continue to emphasize the need to do this in a rational, economic way.

We've asked them to define their specific objectives; we've asked them to embrace the framework they put out there a year ago; and we've asked them to come to us and say what is their expectation of our industry sectors over the next two decades, what is it you want us to do better? We have not had those kinds of conversations. They've not defined a specific objective. They've defined a general framework which we're supportive of.

Now we want them to say that's the framework they have to have in the negotiations. We want them to tell them what their expectations are of our industries. Until we can get that, it's going to be difficult for us to sign onto some blank check Kyoto agreement where we don't know what they are expecting of us or what their implementation regime may be when they bring that agreement back to the United States.

These are reasonable questions for us to ask. We also think it's reasonable information for them to have. It was information we had as we were working through the Montreal Protocol negotiations. We had a better description of implementation schemes and those impacts.

Senator CHAFEE. It certainly seems to me that we should expect in any agreement we entered into that the developing nations are going to be a part of it. I can understand that perfectly well and I think that's a reasonable point you're making.

Mr. O'Keefe, in your testimony you talked about actions being considered by negotiators that would require us to suppress energy use by at least 25 percent in a little over a decade. Where do you get that figure from? Where is that? Is that being seriously considered by our negotiators, requiring a response like that?

Mr. O'KEEFE. Dr. Yellen used as the period 2010 to return to the 1990 levels. In the State Department's report on the voluntary programs, they talk about a 25 or 26 percent reduction. All the independent economic analyses that have been done on the subject assume that the most benign thing that's being considered, that might be agreed to, is returning to the 1990 levels by 2010.

The best estimate is that we would have to suppress, reduce energy consumption of fossil fuels by at least 25 percent below the level being estimated today by the Energy Information Administration.

Senator CHAFEE. From where we'd otherwise be?

Mr. O'KEEFE. Yes.

Senator CHAFEE. Even though that might be more than the 1990 level?

Mr. O'KEEFE. Oh, it will be. We don't have the technology to make that kind of reduction in that short a time period—13 years. I think that Mr. Fay has made the same point.

We need a process that is predictable, that is realistic. The Administration analysis is based on a trading program and some new technology. The technology hasn't been identified and other countries have rejected the trading scheme and many economists believe that it's not feasible. Quite simply, other nations will not agree to it.

Certainly, if it was going to be in place, it's going to take a long time to get an agreement. So it might be better in Kyoto to try and agree on a framework that all nations would embrace and then, at a future conference, decide what the target is and the time period for achieving it.

Senator CHAFEE. As I understand what both of you are saying, both of you recognize that there is a problem there and it's what to do about it where the contention comes. Is that a fair statement?

Mr. O'KEEFE. I think that there is a risk. I think there is legitimate scientific dispute over the problem and the hearing you had last week demonstrated that. The last page in Chapter 8 of the IPCC report, around page 439, makes it clear that there is not a scientific consensus that we have a problem. But that's not an excuse for inaction.

There is a potential risk and there is uncertainty and the uncertainty goes both ways. Given the uncertainty and the potential risk if we guess wrong, there is certainly a need for prudent action, but the people who have also studied this say we do have time to do it right. We do not face an imminent catastrophe that justifies the kind of crash program to reduce energy use that's being considered by the negotiators.

Senator CHAFEE. The problem we have with that is, and we encounter this all the time. I'm on the Finance Committee and we're dealing there with Medicare and we have come up with a proposal that eligibility age for Medicare be increased to 67 to correspond with the eligibility age for social security.

There is great objection to that from many saying no, no, no and we're doing it because there is a real problem out there with the future of Medicare. So those like myself who are proponents for doing something say there's always an excuse to wait and delay things and it's always attractive to postpone it. It seems to me there is a similar situation here.

I hardly think we've rushed into this, but your feeling is, I think you just said, let's wait and do it right. Who knows what right is?

Mr. O'KEEFE. Let me be clear. I'm not saying we should do nothing. There are hundreds of companies that are participating in the voluntary programs. The petroleum industry, which I also represent, is spending over $10 billion a year on achieving environmental objectives. There is a lot of progress being made. It's not whether we act; it's the rate at which we force actions to be taken and the consequences of those.

By taking the time to do it right, and by that I mean the time to turn over the capital stock, get new plants and equipment in op-

eration; and incentives to accelerate our improvement of energy efficiency. We've reduced the energy component per dollar of GDP over the past two decades by 30 percent. Incentives to continue that. And to take our technology and get it in the hands of other nations all take time.

Senator CHAFEE. What are the incentives now? You must be doing it. Your companies aren't doing it because they're worrying about global warming; they must be doing it because being more fuel efficient saves them money. Hopefully that is an incentive.

Mr. O'KEEFE. Well, they learn with new knowledge. We find there are better ways to do it and people take into account potential changes in law and regulation and knowledge. I can't tell you what component of the decision may take into account climate change, but certainly the possibility is taken into decisions when you're making capital investments that will last 20 or 30 years.

Mr. FAY. I think that our companies do also take into account the environmental issues as well, Senator. Our problem is not so much that we've rushed into this that all of a sudden we have these negotiations; our biggest problem I think is that we're 5 months from the supposed deadline and we have some fairly basic issues that this Administration either hasn't talked to us about or hasn't made their own decisions on.

They've come in now after promising for a year this economic analysis and they've come back and said, it's hard. Well, we know it's hard. We have to make hard decisions every day in the private sector.

We need to know what basis are they going to use then to make their decisions. We think it's still possible to achieve a treaty in December, but it's getting harder and harder as the time grows shorter. We don't think a 2-day White House conference is going to help all of a sudden produce the magic answers of what we're going to do on climate change.

Mr. O'KEEFE. It also doesn't help the Senate that has to participate in the advice and consent process.

Senator CHAFEE. Thank you both very much for coming. Your testimony was very helpful and we appreciate you being here.

That concludes the hearing.

[Whereupon, at 12:55 p.m., the committee was adjourned, to reconvene at the call of the chair.]

[Additional statements submitted for the record follow:]

STATEMENT OF JANET YELLEN, CHAIR, COUNCIL OF ECONOMIC ADVISERS

Thank you, Mr. Chairman and members of the committee. I appreciate the opportunity to discuss with you today the economics of global climate change.

INTRODUCTION

In his speech to the United Nations Special Session on Environment and Development in June, President Clinton emphasized that the risks posed by global climate change are real and that sensible preventive steps are justified. This assessment accords with the views of the more than 2,300 economists, including 8 Nobel laureates, who signed a statement supporting measures to reduce the threat of climate change. The economists endorsed the conclusions from last year's report by the Intergovernmental Panel on Climate Change (IPCC), which said that governments should take steps to reduce the threat of damage from global warming, and went on to argue that market-based policies can slow climate change without harming the American economy.

At this time the Administration has not settled on a particular set of new policies to reduce greenhouse gas emissions. Instead, the President indicated in his U.N. speech that he intends to engage in a discussion with all interested parties about the problems posed by greenhouse gas accumulations and the costs and benefits of corrective action. To this end, the President will hold a White House conference on climate change later this year, and members of his Cabinet and other senior Administration officials will meet with Members of Congress, scientific and economic experts, environmentalists, local government officials, and business and labor leaders on a regular basis over the next several months to discuss issues related to climate change. This process is intended to inform the Administration's decisionmaking process, which will culminate in a U.S. policy position in the international negotiations in Kyoto in December of this year.

An important step in this—and any—policy process is determining the impact it will have on the American economy. President Clinton's top priority, since his first days in office, has been revitalizing the U.S. economy, creating jobs and investing in people and technology to enhance long-term growth. And, we have made tremendous progress. The President is not going to jeopardize that progress. Any policy he ultimately endorses on climate change will be informed by his commitment to sustaining a healthy and robust economy.

In my testimony today, I would like to describe some of the principal lessons that emerge from the voluminous literature, much of it relatively recent, on the economic impacts of policies to address global climate change.

UNDERLYING UNCERTAINTIES

Before I begin my discussion of the economic literature, I would like first to acknowledge the uncertainties associated with estimating both the costs and benefits of reducing greenhouse gas emissions. To provide some perspective: as you all know, it is difficult to gauge exactly what impact the balanced budget agreement will have on the U.S. economy's growth rate, levels of employment, interest rates and consumption over the next 5 years. But with global climate change, it is orders of magnitude more difficult to gauge the effects on the economy: we are concerned with not just the next 5 years and not just the American economy, but, rather, we are dealing with economic and physical processes that operate globally and over decades, if not centuries.

Although a great many scientists believe that global climate change is already underway, the more serious potential damages associated with increasing concentrations of greenhouse gases are not predicted to occur for decades. This means that the benefits of climate protection are very difficult to quantify. And, while the potential costs of reducing greenhouse gas emissions may be more immediate, they too, as I will discuss below, are difficult to predict with any certainty. Many unanswered questions exist about the biophysical systems, potential thresholds, and economic impacts. In short, if anybody tells you that he or she has the definitive answer as to the costs and benefits of particular climate change policies, I would suggest that you raise your collective eyebrows.

LESSONS FROM THE ECONOMIC LITERATURE

Let me now turn to the economic literature and try to summarize what I think we know so far about this difficult topic. Most economists have not addressed the benefits of climate protection, but rather have focused on the costs associated with alternative paths for reducing greenhouse gas emissions. The economic literature includes estimates using many different models to evaluate numerous alternative emission reduction strategies. In fact, because there are so many different models, economists initially faced difficulties in comparing results: they could not sort out the extent to which differences in results stemmed from differences in models and assumptions versus differences in baseline emission paths and policies. To solve this problem, thereby enabling meaningful comparisons, many economists have calibrated the various models by performing a standardized simulation. Specifically, they have assessed the consequences of stabilizing greenhouse gas emissions at 1990 levels by 2010 or 2020.

Within the Administration, a staff level working group—the Interagency Analysis Team (IAT)—has attempted to estimate some of the economic implications of climate change policies. They took the emissions scenario most often used in academic literature—that is, stabilizing emissions at 1990 levels by 2010—as the starting point for their own analysis. I would emphasize that this scenario is not Administration policy; instead, it was picked to make comparisons with other models easier. The staff group employed 3 different models—the DRI model, the Second Generation Model (SGM) and Markal-Macro model, all commonly available in the public sphere.

In running these models, the staff adopted a common baseline and, to the—maximum extent possible, similar economic assumptions. This modeling effort produced some useful lessons, but as we found from the peer reviewers' comments, it also suffered from some serious shortcomings. Both the lessons and the shortcomings point to one clear conclusion: the effort to develop a model or set of models that can give us a definitive answer as to the economic impacts of a given climate change policy is futile. Rather, we are left with a set of parameters and relationships that influence estimates of the impacts. In my view, it is more productive to employ a broad set of economic tools to analyze policy options than to seek to develop a single definitive model.

I understand that a draft of the staff analysis was given to the committee earlier this week, along with the reviewers' comments. I would be happy to answer any questions you may have about this modeling effort.

The Lessons

Modeling efforts both inside and outside the Administration clearly indicate that economic analysis can do no more than estimate a range of potential impacts from particular policies and highlight how outcomes depend on underlying assumptions about how the economy works and the ways in which policy is implemented. However, the economics literature on climate change does point to several important lessons:

How the economy works

First, the magnitude of the costs of reducing greenhouse gas emissions in the various models depends crucially on a number of key assumptions about how the economy works. For instance:

- If firms in the economy can shift from high-carbon to low-carbon energy sources quickly, the costs of climate protection will be lower.
- If the economy has significant opportunities, even now, to employ energy-saving technology at low costs, the costs of climate protection will be lower.
- If technological change occurs at a rapid rate, or is highly responsive to increases in the price of carbon emissions, the costs of climate protection will be reduced.
- If the Federal Reserve pursues a monetary policy oriented toward keeping the economy at full employment, transitional output costs will be lower.

In short, the greater the substitution possibilities and the faster the economy can adapt, the lower the costs.

How the plan is implemented

Second, costs depend critically on how emission reduction policies are implemented. It boils down to this: if we do it dumb, it could cost a lot, but if we do it smart, it will cost much less and indeed could produce net benefits in the long run. The over 2,300 signatories of the economists' statement argued that any global climate change policy should be rely on market-based mechanisms. Such mechanisms allow for flexibility in both the timing and location of emission reductions, thereby minimizing the costs to the U.S. economy. The economists concluded that "there are policy options that would slow climate change without harming American living standards, and these measures may in fact improve U.S. productivity in the longer run."

- The speed at which emissions reductions are required can have large effects on the estimated costs. It is important to allow sufficient lead-time for orderly investment in new equipment and technology. Alternatively, if emission reduction requirements are too far off in the future, the incentives to adopt energy efficient technologies are weakened because people may not view the policy as credible.
- A "cap and trade" system in which emission permits are issued and then traded among firms can substantially reduce the cost of meeting an emissions target by creating incentives for emissions to be reduced by those firms and in those activities where costs are lowest.
- International emission permit trading substantially lowers costs by applying the same cost-minimizing principle globally.
- So-called "banking" and "borrowing" of permits increases flexibility and lowers costs by allowing firms to change the timing of their emission reductions.
- Joint implementation, whereby U.S. firms would receive credit for undertaking emission reductions in countries with low abatement costs, would also lower the domestic burden.

An additional aspect of implementation that profoundly affects the costs of reducing emissions concerns "revenue recycling." In many model simulations, emissions are reduced by using various market mechanisms. For many of these scenarios, the Federal Government realizes an increase in revenues. Economic growth can receive

a long-term boost if these revenues are used to reduce distortionary taxes that diminish the incentives to invest, save or work, or if the revenues are channeled into deficit reduction, thereby lowering interest rates and boosting investment. In fact, in some models and scenarios, emissions reduction generates a net economic benefit when the revenues are recycled in a growth-promoting fashion.

Which countries participate

The third lesson that emerges from a study of the economics of climate protection is that developing, as well as developed, countries must be part of the process. While developed countries are responsible for most of the greenhouse gas currently in the atmosphere, developing countries are starting to catch up. By 2040, the largest fraction of emissions is estimated to come from developing countries. Thus, any comprehensive plan to deal with this global problem must include a mechanism to bring developing countries into the process.

The timetable for the inclusion of developing countries is also important. The sooner that developing countries face incentives to move away from carbon intensive energy sources, the less likely it is that they will become dependent on those types of fuels to spur their economic growth. In short, global problems require global solutions. We must find the technologies and solutions to lead the way.

CONCLUSION

Let me conclude. Policies to promote economic growth, create jobs, and improve the living standards and opportunities of all Americans have been and always will remain the top priority of the President and his Administration. In his remarks to the Business Roundtable on global climate change, the President said "[l]et's find a way to preserve the environment, to meet our international responsibilities, to meet our responsibilities to our children, and grow the economy at the same time."

Some of the key economic lessons we have learned that will help us achieve the President's goal include:

- Inherent uncertainty dictates that models should be expected to generate only a range of economic impacts, not definitive answers.
- Key assumptions about how the economy works directly influence the estimated costs of climate protection.
- Implementation of any policy needs to be market-based and flexible over time and space to achieve the lowest cost reductions.
- All nations, both developed and developing, need to participate.

Thank you I would be happy to answer any questions you may have.

RESPONSES BY JANET YELLEN TO ADDITIONAL QUESTIONS FROM SENATOR CHAFEE

Question 1. Dr. Yellen, you indicate at the beginning of your testimony that the Administration, "has not settled on a particular set of new policies to reduce greenhouse gas emissions." We are now 20 weeks away from Kyoto. When will it? Is there still time for informed public review and debate on the options?

Answer. The President, Members of the Cabinet and Senior White House officials have been meeting with a wide range of parties interested in the issue of global climate change. We have been consulting with representatives from business and labor, environmental groups, scientists, economists and others about the best, most cost-effective way to reduce greenhouse gas emissions. On October 6, the White House will hold a conference to discuss the scientific evidence, the economic impact and the international implications of global climate change. These discussions are intended to inform the Administration's decisionmaking process, which will culminate in a U.S. policy position for the international negotiations in Kyoto in December of this year.

With the lessons we have learned so far, the Administration has established a broad framework within which this policy position will be developed. For example, we support the use of flexible approaches, such as international emissions trading. We support the requirement that non-Annex I countries, as they become wealthier, abide by binding emissions goals that are formulated in international treaty negotiations. And, for domestic implementation, we support the use of flexible, market based approaches.

Question 2. You also say in your prepared remarks that, "the effort to develop a model or set of models that can give us a definite answer to the economic impacts of a given climate change policy is futile." How are we to respond? What reliable tools do we have to determine what, if any, agreement is best for the United States?

Answer. No one model, or even a small set of models, can give a definite estimate of the effects of a policy on the economy 20 or 30 years into the future. The existence

of modeling difficulties does not mean, however, that we can abandon rigorous economic analysis. Rather, we must employ a broad set of economic tools, and incorporate insights from the existing body of research on climate change policies, as we analyze the policy options. Some of these may have strengths on issues where the models used in the Interagency Analytical Team (IAT) analysis were weak.

Drawing on this broad array of analytic tools allows an intelligent evaluation of policy alternatives. I am confident that the analytic tools and perspectives available to the Administration can provide us with sufficient information to generate ranges of estimated economic effects so that the Administration can make informed policy decisions.

Question 3. Is the Administration considering some form of new energy tax to administer a new treaty, domestically?

Answer. At this time, the Administration has not settled on a particular set of policies. The Administration is considering an array of market-based approaches to implement climate policy.

Question 4. What advantages or disadvantages (economically or environmentally) might a trading system have over energy taxes?

Answer. Tradeable emissions permits would provide greater certainty than energy taxes of attaining a specified emissions cap. By specifying a number of permits and allowing firms to trade these permits, the country can ensure that it is meeting an agreed upon carbon emissions goal. A tax, on the other hand, would provide greater certainty than a cap-and-trade approach of limiting costs, since the increase in unit costs would be determined by the tax. Taxes and permits may also differ in their administrative and transactions costs and ease of enforcement, particularly depending on how a permit trading system is implemented.

Question 5. In order to use flexibility instruments like the proposed joint implementation and emissions trading, do we need to have a cap on nations' emissions?

To what extent can these instruments reduce the cost of implementation of greenhouse gas emissions reductions for the United States and others? Is there reliable data available?

Answer. For international emissions trading, all countries participating in the trading scheme will need to have their emissions capped. For joint implementation, all countries can participate, regardless of whether their emissions are capped. However, it will be necessary to set standards for approving joint implementation projects sufficient to ensure that the credit received by U.S. companies actually results in incremental abatement activities abroad.

International permit trading allows emission reductions to occur in areas where the costs of those reductions are lowest. If some of the emissions reductions necessary to achieve the U.S. goal can be undertaken in other countries at lower costs, then U.S. emissions control costs will fall, by some estimates as much as two-thirds. While every country is better off when it can voluntarily buy or sell permits according to its respective emissions reduction costs, the ultimate permit price and traded quantities depend heavily on the degree of participation by developing countries and economic growth in Russia and Eastern Europe.

Question 6. Some have argued that innovation toward less greenhouse-intensive technologies will occur in the absence of any market signal. Do you agree? Why or why not? If a market signal is needed, how should it be provided?

Answer. Some shift toward a less energy-intensive economy occurs in the absence of deliberate government influences on price, some believe because of the changing composition of the U.S. economy toward less energy-intensive sectors. Many studies suggest that energy use relative to GDP falls each year, regardless of the price signal, by 0.5 to 1.25 percent. To the extent that energy use is associated with climate change effects, and in turn causes damages not reflected in market prices, the business-as-usual decline in energy use relative to GDP is unlikely to be sufficient. Additional incentives to innovation, such as price signals or support for R&D may be needed.

Question 7. Many are concerned that caps on industrialized nations' emissions, without similar caps on developing nations' emissions, will simply promote the flight of jobs, capital, and polluting activity to developing nations. Is this a valid concern? How should it be addressed? Would joint implementation help?

Answer. Certainly the participation of developing countries is key to the long term success and cost-effectiveness of a global reduction in greenhouse gas emissions. In the next century, developing countries will likely reach and surpass currently developed countries in their share of global emissions. Any emissions reductions that Annex I countries achieve can be undone by others who do not so carefully address

the problem. In addition, the important opportunities for low cost reductions created by developing countries' participation could reduce the overall cost of achieving a given environmental goal by more than a half by some estimates.

Some observers of the climate change issue have suggested that capping only developed countries' emission will result in "leakage": the escape of jobs, capital, and polluting activity to developing countries. Even if caps are not initially placed on developing countries' emissions, the economic evidence does not support the argument that sensible climate policies will adversely affect overall U.S. economic competitiveness.

First, non-tradeable sectors account for a substantial share of carbon emissions. Transportation and residential and commercial buildings account for approximately two-thirds of U.S. carbon emissions. For these sectors, the "competitiveness" argument does not appear applicable. Second, energy costs comprise only a small percentage of total manufacturing costs. According to the 1995 Annual Census of Manufactures, energy costs for manufacturing industries averaged just 2.2 percent of total costs. Given the small share of energy in total costs, differential shifts in existing energy prices are unlikely to have substantial effects on location decisions and trade flows. Third, our experience in this country with environmental regulation has been that it does not cause significant leakage. Firms that decide to relocate to other countries do so because of international differences in input costs and exchange rate changes that all swamp the costs of complying with environmental regulations.

RESPONSES BY JANET YELLEN TO ADDITIONAL QUESTIONS FROM SENATOR BOXER

Question 1. In the Administration's economic analysis, it is stated that, "There is no evidence of a wholesale 'capital flight' from the United States resulting from an emissions reduction policy." Can you please expand on this?

Answer. Certainly the participation of developing countries is key to the long term success and cost-effectiveness of a global reduction in greenhouse gas emissions. In the next century, developing countries will likely reach and surpass currently developed countries in their share of global emissions. Any emissions reductions that Annex I countries achieve can be undone by others who do not so carefully address the problem. In addition, the important opportunities for low cost reductions created by developing countries' participation could reduce the overall cost of achieving a given environmental goal by more than a half by some estimates.

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Question 2. The United States has far lower energy costs than Europe and Japan. How would our costs of emission reductions compare with theirs? How would this affect our ability to compete?

Answer. The costs of reducing emissions in the United States, and in Europe and Japan, depend on how all of these countries implement their policies. If the United States employs a market-based approach, the costs will not be that high relative to Europe and Japan. Regardless of the implementation approaches used in these countries, the costs of emissions reductions are not likely to affect U.S. competitiveness. As noted above, energy costs comprise a small share of total manufacturing costs (2.2 percent). Further, two-thirds of carbon emissions occur in non-tradeable sectors. The evidence on energy price differentials across countries suggests that they are not sufficient to spur firm relocation to other countries.

Several analyses indicate that Western Europe will bear *higher* costs for reducing carbon emissions than will the United States. Western Europe already has high energy taxes relative to the United States, and has already "backed out" of fossil fuel use to varying degrees. This implies that a lot of the less expensive measures for reducing carbon reductions have already occurred in Europe, so that the United States has relatively more opportunities to inexpensively cut carbon emissions. For example, 20 percent of all energy in France, and a majority of its electricity production, is from nuclear power, while only 7 percent is from coal. Since nuclear is not carbon-based, France cannot further reduce carbon emissions from that energy source, and can achieve relatively limited emissions reductions from its low use of coal. In contrast, in the United States nuclear power comprises only 9 percent of total energy production, while coal comprises 23 percent.

Question 3. Dr. Yellen, we have heard horror stories of all the catastrophic economic effects that embarking on a policy of reducing greenhouse gas emissions would cause. Did the administration's analysis consider the positive effects on health, environment, *AND* the economy that reducing greenhouse gases would produce?

Answer. The IAT report did not assess the human health and environmental benefits of reducing greenhouse gas emissions. In addition, the IAT did not study the risks of effects of climate change on economic activity. However, the report did assess the impacts of climate policy on the economy. The IAT analysis confirms other economic research (for example, the recent report by the World Resources Institute) that smart climate policy could produce some benefits for the economy. For example, the IAT analysis found that auctioning off tradeable permits and using the proceeds of the auction to reduce other taxes that distort work and savings decisions could produce economic benefits that offset the costs of meeting a climate change goal.

Question 4. We heard last week that the longer we wait to implement our reductions, the more costly it will be in practically all sectors—health, environment, and jobs. This reminds me of the commercial where the grizzled mechanic says, "You can pay me now, or you can pay me later." What did your analysis find in terms of the costs of delaying action?

Answer. We believe it is important to take early, credible action toward a long term strategy to control greenhouse gas emissions. More gradual efforts to reduce our carbon emissions can significantly lower the economic costs relative to very aggressive reductions efforts while still achieving the same carbon dioxide concentration goal. For example, some international proposals to reduce carbon emissions would have Annex I countries cutting emissions to 20 percent below 1990 levels by 2005. Such a target and timetable would have very substantial economic costs because it does not provide enough time for the capital stock to turn over. It is very expensive to prematurely scrap the existing capital stock while much of it is in the prime of its life. Further, such a goal would require the economy to employ existing low-carbon and carbon-free technologies while longer-term reductions would provide more lead time to develop and implement superior technologies. Given that it is the stock of carbon dioxide, not the annual emissions of carbon dioxide, that drive global warming, flexibility in the timing of emissions reductions can lower costs while not undermining our commitment to achieving a given ultimate concentration.

Question 5. California has been a leader in development of new energy technologies. Based upon your analysis, what industries are likely to grow over the next 20–30 years?

Answer. It is very difficult to forecast the nature of the economy, especially specific industries, 20 or 30 years into the future. If the country embarked on a policy of reducing carbon emissions, obviously the firms and industries that can creatively and cost-effectively reduce their emissions will benefit relative to their competitors. It is reasonable to envision that the products and services of industries that develop energy efficient technologies and industries that develop low-carbon based energy (such as renewable energy sources including wind, solar, and biomass) would be in greater demand during a period of reduction in greenhouse gas emissions.

RESPONSES BY JANET YELLEN TO ADDITIONAL QUESTIONS FROM SENATOR LIEBERMAN

Question 1. Congressman Dingell suggested on 6/19/97 that the Administration's analysis is "too late to inform the process, and likely will be used to justify what the Administration has already decided to do." Please comment on his concerns.

Answer. The Administration's analysis on the issue of climate policy has not occurred in a vacuum. In fact, climate change has been one of the more active areas of research in economics this decade. The economic literature on climate change,

complemented by the IAT report, has already done quite a lot to inform the policy development process. Based on the economic research, we have identified some of the important characteristics of the climate policy we will develop: international emissions trading, developing country participation, emissions budgets, and market-based, flexible domestic implementation. My interpretation of the role of economics differs—I believe economics has informed the process, and I am confident that it will continue to play an important role in our country's deliberations over a climate policy position.

Question 2. If the economic impacts of climate policies cannot be determined precisely, how will the economic analysis be used to develop the Administration's specific positions on a target and a timetable? Can the relative costs of different policies be evaluated with confidence by the Interagency Team?

Answer. No one model, or even a small set of models, can give a definite estimate of the effects of a policy on the economy 20 or 30 years into the future. The existence of modeling difficulties does not mean that we can abandon rigorous economic analysis. Rather, we must employ a broad set of economic tools and incorporate insights from the existing body of research on climate change policies, as we analyze the policy options. Some of these may have strengths on issues where the models used in the Interagency Analytical Team (IAT) analysis were weak.

Drawing on this broad array of analytic tools allows an intelligent evaluation of policy alternatives. I am confident that the analytic tools and perspectives available to the Administration can provide us with sufficient information to generate ranges of estimated economic effects so that the Administration can make informed policy decisions.

STATEMENT OF THE TIMOTHY E. WIRTH, UNDER SECRETARY OF STATE FOR GLOBAL AFFAIRS

Chairman Chafee and members of the committee, I am pleased to be with you today to discuss the ongoing negotiations toward next steps under the United Nations Framework Convention on Climate Change. These negotiations began in August 1995 and are scheduled to end in December, at the Third Conference of the Parties in Kyoto, Japan, with the adoption of a new protocol or other legal instrument.

In his address last month to the United Nations General Assembly Special Session, President Clinton noted that "[t]he science is clear and compelling" and committed the United States to strong leadership on climate change. The President committed himself to engage the American people and the Congress in a dialog to explain the real and imminent threats from climate change, the economic costs and benefits involved, and the opportunities that American technology and innovation can provide. The President also committed to "bring to the Kyoto conference a strong American commitment to realistic and binding limits that will significantly reduce our emissions of greenhouse gases."

In recent weeks, interest in the negotiations has intensified, particularly in the Congress. The Administration welcomes this interest, wants to encourage the broadest possible dialog as we work toward a new agreement in Kyoto, and urges the Senate and House leadership to establish observer groups with whom we can work even more closely in the weeks and months ahead.

I would like today to focus on two concerns—first, how the actions we are negotiating under the Climate Convention correspond to a specific environmental objective; and second, the need for developing nations to acknowledge more fully their role in meeting that objective.

I would like to begin with the science, because scientists were the ones who drew our attention to climate change in the first place, and because we continue to base our policies on the best evidence and the most rigorous scientific analysis available. While I know many of you are aware of the basic facts, I think it may be useful to reiterate a few of the most crucial points that the scientific community has established.

The "greenhouse effect" is caused by gases such as carbon dioxide, methane and nitrous oxide, which accumulate in the atmosphere and trap solar radiation, thus making the planet warmer than it otherwise would be. The natural levels or concentrations of these greenhouse gases in the atmosphere keep temperatures within a range that can support life. Without the background level of greenhouse gases in our atmosphere, the earth's temperature would be about 33 degrees Celsius cooler.

Human beings increase the concentrations of greenhouse gases in the atmosphere primarily by the burning of fossil fuels—coal, oil and natural gas—and through a number of other industrial processes. Changing land use patterns, particularly de-

forestation and soil erosion, also play a role, by reducing the capacity of the natural environment to absorb carbon from the atmosphere. Since the industrial revolution in the 18th century, the concentration in the atmosphere of carbon dioxide has risen 30 percent; during the same period, methane concentrations have doubled, and nitrous oxide concentrations have risen by about 15 percent.

Since pre-industrial times, the Earth has warmed about one degree Fahrenheit. Scientists believe that the observed increase is unlikely to be entirely natural in origin. In its most recent scientific assessment, the Intergovernmental Panel on Climate Change (IPCC) concluded that the balance of evidence suggests "a discernible human influence on the climate system."

Projections of future climate change, based on complex climate models and on our best understanding of the physics of the climate system, suggest a rise of another 2 to 6.5 degrees Fahrenheit by 2100, with an average increase greater than any seen in the last 10,000 years. This warming will not be uniform—it is likely to be greater at higher latitudes and at the poles.

Based on these warming trends, sea level is projected to rise an additional 1.5 feet by 2100 due to thermal expansion of the oceans and to the melting of glaciers and ice sheets. This would, without adoptive measures, flood 9,000 square miles of coastal areas here in the United States, notably in Florida and Louisiana, and put about 100 million people worldwide at risk each year from storm surges.

In other words, the path we are on is cause for significant concern. Climate change is likely to have wide-ranging and mostly adverse effects on human health. Both natural and managed ecosystems are at risk. The viability and location of forest and agricultural zones will change significantly.

Moreover, virtually all the studies on the effects of climate disruption have focused on predicted doubling of atmospheric concentrations of greenhouse gases. But unless significant actions are taken early in the next century, it is very likely that atmospheric concentrations will, by the year 2100, nearly triple the pre-industrial level and rise higher than any point in the last 50 million years. Changes to our climate system would also continue beyond the effects that the current studies predict; the risks would increase dramatically as concentrations continue to rise. Moreover, there is no reason to believe that these additional effects would be linear; they would most likely take unpredictable and highly undesirable paths.

Let me now move on to the division of responsibilities between developed and developing countries.

As I noted earlier, we know that man-made emissions have increased the concentration by about 30 percent, from 280 parts per million in pre-industrial times to around 366 ppm today. We know that the industrialized countries have put most of the carbon into the atmosphere, and that CO_2 lingers there for 100 to 150 years. We know that the United States is the largest emitter of greenhouse gases; we have 4 percent of the world's population and contribute 22 percent of the carbon. We also know that, given current trends, the developing world will pass the developed world as an emitter in about 30 years. (At that point, the developing world will have about 70 percent of the world's population.) China, with its 1.2 billion people, will probably pass the United States toward the end of the first quarter of that century.

So action by industrialized nations alone will not put us on the road to safe concentrations of greenhouse gases; we need action by the developing countries as well. But it is very clear from all our discussions and negotiations to date that if the developed countries, with our current economic capacity, technical capability, and energy intensive life-style, don't go first—setting the example and reducing emissions—then developing countries will not act either. We must lead the way. And we must move soon. If not, a doubling of concentrations becomes certain, and we put ourselves on the road to a tripling or even higher levels of concentrations—the consequences of which are uncertain but likely to be catastrophic.

In 1992, the world community adopted the United Nations Framework Convention on Climate Change in an effort to begin coming to grips with this environmental threat. Under the Convention, developing nations agreed to take a variety of actions to mitigate climate and to facilitate adaptation to it's consequences. Industrialized nations agreed to take the same actions, but in addition, they agreed to take steps aimed at returning their emissions of greenhouse gases to 1990 levels by the year 2000.

In 1995, the Parties to the Climate Convention decided the existing treaty commitments were not adequate to address the threat. Accordingly, they agreed to begin a process to negotiate next steps. Since the "aim" set for industrialized nations expires in the year 2000, they began to consider the goals that should guide their efforts in the decade or two after the year 2000. Industrialized nations agreed to establish quantified targets to limit and reduce their greenhouse gas emissions over yet-to-be-determined time periods—such as 2005, 2010 or 2020. At that time, devel-

oping nations, many of whom had only begun to implement their existing commitments under the Convention, argued strenuously that the negotiating process should not result in new commitments for them. They agreed, however, to continue to advance the implementation of their existing commitments.

The U.S. proposals in the current negotiations attempt to move the process. The U.S. proposal acknowledges that the list of "developed country Parties" established by the Convention's Annex I in 1992 no longer reflects current realities. A number of developing countries have joined the ranks of the developed world, through membership in the OECD and in other ways, and more are poised to do so. Our proposal to establish an "Annex B" would enable such countries, on a voluntary basis, to move beyond their current non-Annex I status, and take on binding greenhouse gas emissions obligations, reflecting their rapidly changing economic status, and enabling them to engage in emissions trading with industrialized nations.

Similarly, Article 16 of the U.S. proposal calls on developing country Parties to adopt, by 2005, binding provisions so that all Parties have quantitative greenhouse gas emissions obligations and so that there is a mechanism or "trigger" for automatic application of those obligations, based on agreed criteria.

In urging this policy of "evolution," the United States is far out in front of almost all other countries, and we are being criticized accordingly. For example, several developed countries believe that our proposal imposes unfair burdens on developing countries. Most countries in the developing world believe that "evolution" goes beyond the scope of the Climate Convention and the Berlin Mandate. We think we have the concept about right: no one should be exempt; we emit the most, so we have to act first; but others have to phase in over time.

The overall negotiation on climate change is extremely complex—the most complex I have seen in 25 years of public life (including 12 years on this challenging committee!)—and the "evolution" aspect is perhaps the most important of all. We have put forward some proposals; some in Congress have as well. Now we have to hammer out a final proposal and negotiating position. We welcome your input, support and creativity as we work to solve this problem, and I look forward to hearing your ideas, questions and comments today.

The issue is not whether developing countries, especially the big and rapidly developing ones, take on quantified commitments to limit or reduce their emissions of greenhouse gases clearly, it will be impossible to abate the threat of climate change unless they do. The issue is when such commitments should begin, and what criteria should be used to establish them, and to whom they would apply.

There are significant disparities in national income between those in industrialized nations and those in developing nations. There are enormous differences in per capita levels of greenhouse gas emissions. Some developing countries argue that these gaps must narrow before they will accept quantified emissions limitation or reduction commitments.

While this argument is understandable, it misses two key points. First, the environmental threat posed by global climate change cannot be averted if nations wait to act until levels of national income or per capita emissions converge at some theoretical point in the future. Second, industrialized nations simply will not make significant efforts to reduce their greenhouse gas emissions if their efforts will be undermined by an unlimited increase in emissions from the developing world.

The Framework Convention, which President Bush signed and to which the Senate overwhelmingly gave its advice and consent, established the principle that, with respect to climate change, the world's nations have common but differentiated responsibilities and varying capabilities. Insisting that developing nations immediately accept binding emissions targets that industrialized nations are seeking to negotiate for themselves is neither realistic nor consistent with the Convention approved by the Senate. But insisting that those developing nations now responsible for a growing share of global greenhouse gas emissions should have no further obligations to act until they have crossed some threshold of national income or emissions on a per capita basis is equally unrealistic and inconsistent with the Convention's ultimate objective.

The agreement reached in Kyoto will not solve the problem of global climate change. No matter how ambitious, it will represent only a second step along the much longer path toward achieving the Climate Convention's ultimate objective. As we prepare for Kyoto, we must also prepare for further steps beyond it. In particular, we must ensure that all nations responsible for a significant share of current global greenhouse gas emissions accept the need to limit or reduce their emissions, and that they begin to move in that direction.

What a Kyoto agreement can do is provide nations with the tools they will need to achieve to achieve significant, binding greenhouse gas limitation and reduction commitments. These tools include greenhouse gas emissions budgets over multiyear

budget periods that will help smooth out annual fluctuations. They include full national flexibility in the choice of policies and measures to meet such binding emissions budgets. They include emissions trading among nations with binding emissions budgets, with the participation of the private sector in the trading regime, to help lower the costs of compliance. And they include joint implementation for credit between nations with binding emissions budgets and those that do not yet have such budgets both to lower the costs of compliance and to promote economic development and environmental protection.

Mr. Chairman, we have indeed charted an ambitious course for the months ahead. The tremendous risks to our planet demand nothing less. With your continued support and the support of other Members of Congress, I am confident that we will obtain an outcome in Kyoto that will represent a significant step forward on the much longer path toward safeguarding the Earth's climate system for present and future generations. Thank you, Mr. Chairman.

STATEMENT OF KEVIN J. FAY, EXECUTIVE DIRECTOR, INTERNATIONAL CLIMATE CHANGE PARTNERSHIP

Good Morning, Mr. Chairman and members of the committee. My name is Kevin Fay; and I serve as the Executive Director of the International Climate Change Partnership (ICCP), a coalition of U.S. industry representatives and associations, as well as international associations, interested in the policy development process with respect to global climate change. We appreciate the opportunity to appear before the committee today on the subject of a global climate change convention.

ICCP was organized in 1991 to provide a forum to address the issue of global climate change and to be a constructive participant in the policy debate. Five months before the Third Conference of Parties meeting in Kyoto, the issue has certainly raised the interest of many of us in the private sector and the Congress.

ICCP continues to recognize the climate change issue as an important matter with which governments should be concerned. However, it is a very long-term issue and extraordinarily complex in both its underlying science and its entanglement with the very foundations of the global economic structure.

We have recently communicated our views on the key issues in the Kyoto negotiations to the Administration. I am attaching this correspondence to my testimony and ask that it be included in the record. We have also communicated to the President on the issue of the Administration's as yet unreleased economic analysis, expressing our frustration at their lack of communication on the matters of greatest concern to the private sector—namely the potential economic impacts of a climate change agreement and the current thinking of future implementation scenarios. This letter is also attached.

Our views have been based on the premise that the only agreement that is acceptable is one that is comprehensive and can work with flexibility, maintain national sovereignty, ensure participation by all countries, maintain a competitive level playing field, and is guided by effective science and includes a long-term objective that will guide future policymakers and future negotiators.

You will note that in both letters, we urge the President and the State Department to reiterate to our negotiating partners that the U.S. policy framework enunciated last July is the only framework that can provide a climate change agreement that is both environmentally beneficial and economically feasible.

Since prior to the first meeting of the parties in Berlin, we have consistently argued that the time is not yet right for a climate change agreement. Unfortunately, the parties established an artificial deadline under the Berlin mandate to reach an agreement by the third meeting of the parties, now scheduled to be held in December of this year.

In our view the Administration made progress in its own deliberations and offered a thoughtful policy framework at the second meeting of the parties in 1996 which we have heard about here today. This policy outline includes a comprehensive approach; identification of a long-term objective; identification of a developing country role under the treaty; implementation flexibility through emissions trading, banking, and joint implementation; and avoidance of a laundry list of so-called "policies & measures."

The U.S. framework also included a call for a binding commitment, which the Administration has subsequently defined as an emissions budget period of undetermined length to achieve reductions of an undetermined size. While most of the attention has been focused on this part of the discussions, we continue to believe that it is not the only key to a successful treaty agreement in Kyoto or beyond Kyoto.

We should point out at this time, however, that we have been provided with no analysis to justify any particular target or timetable that might be advocated.

Our primary concern has been that the result of the negotiations would focus on only one or two of the key issues, some of which we have outlined in our letter, and that the rest would be left until later. This would be unacceptable to us. This worst result would be for the Administration to agree to some target and not achieve the entire policy framework it has advocated.

An agreement on a target and timetable in Kyoto, and nothing else, would be unacceptable to the ICCP. An agreement in Kyoto on a target and timetable, including a developing country schedule, but with none of the flexibility or other provisions as articulated last year by the Administration, would be just as unacceptable.

To date, we have been disappointed in the progress on most of these fronts and we are pessimistic on the ability to achieve them between now and Kyoto absent strong signals by the White House to reinvigorate the negotiations. ICCP is not and never has been interested in an agreement at the Kyoto meeting just for the sake of reaching an agreement. This view will not change.

With respect to the economic issues and the impacts of a climate change agreement on the U.S. economy, jobs, and the environment we remain very concerned. It is difficult to address this issue in any effective way given the lack of dialog on these topics and the lack of information being provided by the Administration. We know that the economic analysis that has been performed tells us several important things:

- that there are costs involved in reducing greenhouse gas emissions;
- the costs are likely to be reduced if flexibility provisions are incorporated;
- that you cannot achieve any reasonable goals either environmentally or economically without developing country participation; and
- the costs are less if you avoid premature capital retirement or turnover, and provide industry the opportunity to manage their way into the technological innovation that will be necessary to accomplish whatever long-term goal is established by the parties to the convention.

It is difficult to know how the costs compare to the benefits because we have yet to see any analysis that includes the benefits of mitigating climate change or facilitating adaptation strategies.

In order for there to be an effective treaty, we believe that the parties must first get the treaty structure correct. We have a long way to go before that will happen.

In closing, I believe it is useful to look at previous examples for guidance that may provide a better perspective than the intense pre-Kyoto focus. More than 12 years ago, negotiators were struggling to complete the Vienna Convention for Protection of the Ozone layer after more than 5 years of negotiation.

These negotiations had taken on a bitter tone as parties, including the United States and European Union, tried to push for adoption of their own preferred policy approach to dealing with ozone depleting compounds. Instead the parties agreed to the convention and to establish a series of workshops and information gathering devises to better understand each other's views.

When negotiations resumed, the parties were much better informed, and a treaty structure was adopted that has since been proven very durable. The Montreal Protocol, signed in 1987, has proved much more effective than most of us thought possible at the time.

We raise this example not because we believe the issues are identical. They are not and climate change is far more complex. We raise it because as we reach a fevered pitch prior to Kyoto, we want to stress that an effective framework is what counts, not an expedient framework.

A climate treaty needs to be durable for the next 100 years. Our companies have determined that the current State of scientific understanding requires a prudent long-term approach to address this issue. This view is equally applicable to the negotiations themselves.

We appreciate the opportunity to appear before you today, and we look forward to answering your questions.

INTERNATIONAL CLIMATE CHANGE PARTNERSHIP,
June 6, 1997.

Hon. TIMOTHY WIRTH,
Under Secretary of State for Global Affairs,
Department of State, Washington, DC.

DEAR MR. WIRTH: You have requested our views on specific issues under consideration as part of the negotiations on implementation of the Berlin Mandate for a pos-

sible protocol or other legal instrument to the Framework Convention on Climate Change. We are pleased to provide these comments on specific issues of concern to the members of the International Climate Change Partnership (ICCP) with respect to the treaty negotiations. We are also writing, however, to express our concern with the current lack of focus to the negotiations or linkage of these issues with the important relationship between the international treaty and domestic implementation schemes.

ICCP continues to recognize the climate change issue as an important matter with which governments should be concerned. However, it is a very long-term issue and extraordinarily complex in both its underlying science and its inextricable entanglement with the very foundations of the global economic structure. We are concerned that this complexity is exposing an overly ambitious timeframe for current negotiations and that the cohesive activity necessary to ensure a viable foundation for future action under this important treaty simply has not come to be. It is equally disturbing that there has been little public discussion of the economic impacts of the range of climate change mitigation by any of the parties, including the United States.

ICCP commended the U.S. position enunciated in its statement in July of last year as a reasonable framework, and was particularly supportive of its efforts to force into the negotiations greater focus on the long-term character of the issue and its economic implications. However, we have made clear that our support is for the entire framework, and not for individual components. Some have misconstrued this position as support for early targets and timetables. It would be incorrect to read our position as such. While ICCP members have recognized the possibility that negotiators would agree on a mid-term emissions target, we could not specifically support such a target given the current lack of understanding of the implications of such a target or how it would be implemented.

In our view, the issue of a binding target is not the most critical element of the negotiation. We view it more important to provide definition to the treaty structure through a long-term objective and a mechanism to ensure that all parties, developed and developing, have clearly defined roles before we enter into a binding commitment period. It is also important that the parties are able to achieve these goals with flexibility through emissions trading, banking, and true joint implementation. We appreciate that the United States has recognized this need for flexibility.

It is of great concern to us that little progress appears to have been made on many of these issues concerning flexibility and the role of developing countries. While the United States has elaborated its views on these positions in subsequent statements and its protocol draft, we have detected little movement by the other parties on these issues. Since we are not privy to your bi-lateral discussions or the behind the scenes meetings, it is difficult for us to determine the current status of these topics.

It is not acceptable to us for the negotiations to conclude in December with an agreement on a binding commitment toward a mid-term target with all details on other key provisions to be negotiated later.

As you recall, we have consistently expressed our view that 1997 is too soon for a credible technical assessment process which would support an agreement by the parties on these issues. The apparent lack of progress to date, the dearth of information available to us regarding how these issues may be resolved, and the failure to thoroughly discuss the economic implications for an agreement, have only served to confirm this view.

We have pledged to work responsibly with the United States and other parties on the development of an effective framework to address the climate change issue consistent with the need for all nations to sustain economic growth. We remain committed to this principle. It is not clear, however, that these issues can be resolved satisfactorily by the Kyoto meeting. ICCP will, of course, reserve any judgment on the results of Kyoto for the implementation process.

We urge the United States to remain focused on and committed to delivering concrete results on all the points outlined in the statement delivered last July and elaborated on in its subsequent submittals. Further, we believe that the United States should indicate its commitment to its proposed climate change policy structure at the upcoming meetings of the G–7 and the United Nations General Assembly Special Session on the Environment.

Concurrently, we believe the economic impacts of a possible agreement should be communicated with industry and other policymakers so we can have an effective dialog. Failure to discuss some of these issues in advance will make it extremely difficult to build support for ratification and implementation of the international agreement.

We look forward to working with you and appreciate the opportunity to discuss the specific views on the attached position paper in the very near future.

Sincerely,

KEVIN J. FAY,
Executive Director.

INTERNATIONAL CLIMATE CHANGE PARTNERSHIP,
June 6, 1997.

President WILLIAM CLINTON,
The White House, Washington, DC.

Dear MR. PRESIDENT: On behalf of the International Climate Change Partnership, I am writing to express our concern for the status of the economic analysis for purposes of the international negotiations on climate change and the apparent lack of progress in making the economic issues an integral part of these negotiations. The ICCP is a coalition of companies and industries around the world committed to responsible participation in the climate change policy process.

ICCP continues to recognize the climate change issue as an important issue with which governments should be concerned. However, it is a very long-term issue and extraordinarily complex in both its underlying science and in its entanglement with the very foundations of the global economic structure. ICCP commended the U.S. position enunciated in its statement in July of last year as a reasonable framework, and was particularly supportive of its efforts to give the negotiations greater focus on the long-term character of the issue and its economic implications.

It is disturbing to us that, for nearly 1 year, there has been little public discussion of the economic impacts of the range of proposed climate change mitigation strategies by any of the parties, including the United States.

The Administration had promised the results of its economic analysis to the Congress, its negotiating partners, the private sector and the non-governmental organizations. While we applaud the recognition of the need to peer review this work, the slow pace at which this activity is occurring raises concerns that it is either not being seriously pursued, or that the results are not being shared. Neither of these reasons, if true, bodes well for constructive private sector support of the Administration's efforts or for any result produced from the Third Conference of Parties meeting to be held later this year in Kyoto.

This matter is further complicated by the recent resignation of Under Secretary of Commerce Ehrlich, who was coordinating the analytical effort. His departure suggests a possible further loss of momentum on this important effort at a critical time.

Those who may be able to provide constructive input into the analysis and assessment being pursued by the Administration wonder what must be done to understand how specific industry sectors are being examined and what steps are being contemplated in order to pursue your climate protection goals. At a minimum, the Administration should be able to immediately publish the policy assumptions being used for individual sectors.

In addition, aside from frequent references to implementation of flexible, market-based approaches, there has been little discussion of what may be suggested as implementation steps for a Kyoto agreement. Failure to discuss some of these issues in advance will likely make it difficult to build support for ratification of the international agreement and for development of implementing legislation.

We respectfully urge you the Administration to provide an outline of the economic information and policy considerations, as well as a meaningful timeframe for the release of this information.

Finally, we understand that you are preparing to attend the meetings of the G–7 and the United Nations General Assembly Special Session on the Environment. We urge you to reiterate the United States' support for these key economic issues as critical elements of any future agreement on climate change. It is only with these key policy provisions that we will have a climate change agreement that is both environmentally beneficial and economically feasible.

Sincerely,

KEVIN J. FAY,
Executive.

INTERNATIONAL CLIMATE CHANGE PARTNERSHIP VIEWS ON KEY ISSUES IN THE CLIMATE CHANGE PROTOCOL NEGOTIATIONS (IN ALPHABETICAL ORDER)

DEVELOPING COUNTRY ROLE

The United States has outlined a specific proposal for dealing with the developing country role as part of the Kyoto agreement, including definition of obligations under Article 4.1 of the Framework Convention, establishment of an Annex B of countries which would voluntarily adopt emissions budgets, and a date certain by which all parties would have emissions budgets.

As stated by Bert Bolin, Chairman of the Intergovernmental Panel on Climate Change (IPCC) at the March 1997 meeting of the Subsidiary Body on Science and Technological Advice (SBSTA) in Bonn, "[I]t is obvious from this graph that no reasonable future reductions by Annex I countries would stabilize global emissions." Therefore, it is imperative that developing countries be part of this agreement. Furthermore, as stated in the Administration's recent economic work, a significant percentage of infrastructure and industry investment by developed countries is occurring in developing countries. Finally, because of the strong linkages' between population growth and greenhouse gas emissions, it is important that we recognize that seven of the current non-Annex I countries represent two-thirds of the world's population.

The Administration has been forthright in its insistence that the developing country role be defined. ICCP recognizes the potential limits of the current Berlin Mandate with respect to new commitments for non-Annex I Parties. It is clear, however, that the Berlin Mandate contemplates definition and elaboration of Article 4.1 commitments for all Parties, including the developing countries.

Additionally, it is imperative that additional developing country participation, including emission budgets, must be defined prior to the start of the first binding budget period for the current Annex I parties. It is only through such definition that governments and the private sector can ensure that investment flows are not distorted.

ENTRY INTO FORCE

ICCP has noted that six countries, including India and China, currently account for 55 percent of greenhouse gas emissions. In order for the treaty to enter into force, it is imperative that a significant percentage of greenhouse gas emissions be represented by ratifying countries. In addition, a significant percentage of Annex I countries and developing countries should ratify the treaty before it enters into force.

We also believe that it is inappropriate for a regional economic organization to be allowed to represent both itself and the voting rights of its individual members. The EU has argued that it should be allowed to bubble its emissions and is proposing to allocate emissions internally. It is unfair that the EU be granted this concession to bubble its emissions when it declines to support similar flexibility for other Parties. Therefore, the EU should have to decide to either bubble and count as one vote, or to not bubble and to be counted individually.

GREENHOUSE GAS COMPREHENSIVE APPROACH

The protocol negotiations should continue to focus on a comprehensive approach at the international level. Recent proposals from the European Union suggested a protocol on only three gases—carbon dioxide, methane, and nitrous oxide—with the notation that fluorocarbon compounds should be covered by policies and measures and added to the basket in the year 2000. ICCP strongly opposes the EU approach. The gases that can be measured should be covered simultaneously in a comprehensive manner. The key to a comprehensive approach is for Parties to focus on achieving the most efficient emission reductions possible; and therefore, it is unproductive to segregate gases from coverage until a later date or to treat gases differently in an international agreement.

LONG-TERM OBJECTIVE

ICCP has urged the negotiators to provide for a long-term focus or objective. We believe such an objective provides clarity to negotiators, as well as to those charged with implementation of commitments. It is our understanding that the United States has performed some analysis of this issue, and that such analysis could be useful to the negotiators currently. Furthermore, we applaud the article in the U.S. protocol proposals which contemplates a long-term objective.

This objective will be an important guide to future decisionmaking, including private sector investment planning. We note that several participants, including the EU, and certain environmental organizations have suggested certain objectives characterized as atmospheric concentrations of greenhouse gases, and that the IPCC documents present their analysis according to atmospheric loading of greenhouse gases measured in parts per million (ppm) of CO_2 equivalent.

ICCP has not advocated a greenhouse gas concentration as the appropriate measure for the long term objective. A long-term objective could be defined as a combination of adaptation, impacts, and concentration measures.

Recent analysis of the economics of climate change controls have indicated that the long-term objective is not as relevant as the path charted for the emission reduction. In our view, it is impossible to develop a meaningful path without knowing the point of departure and the intended goal.

We recognize that the current State of science does not provide a precise "correct" answer. Science does provide a basis for making an informed political judgment on the objective, and scientific assessment through the IPCC and elsewhere is critical to future reassessment of any potential long-term objective.

POLICIES AND MEASURES

It is imperative that each Nation maintains maximum national flexibility with respect to implementation of its climate commitments. It is neither appropriate nor productive for the negotiators to determine the manner in which each country should achieve its commitments. ICCP is opposed to any listing of specific annexes of policies and measures in any manner, i.e., mandatory, regional coordination, voluntary, or exemplary.

TARGET/BUDGET/ACCOUNTABILITY PERIOD

There have been several proposals for specific point targets and/or budget periods as part of the protocol proposals that are currently before the Parties. ICCP has not endorsed the notion of a binding "target." We do, however, recognize that all of the government proposals to be considered in Kyoto do contemplate such a step as a starting point.

The lesson from the non-binding commitment of the 1992 FCCC agreement is that, despite the best of intentions, a specific point target is very difficult to administer due to fluctuations in economic conditions, weather conditions, etc. Therefore, we believe it is imperative that the long-term objectives be utilized to examine a reasonable path that minimizes short-term economic disruption and stimulates the longer-term technological innovation necessary to significantly reduce worldwide greenhouse gas emissions.

The United States has indicated a preference for an emissions budget period and a binding commitment to achieve that budget. In our view, the practical timetable for ratification and implementation of a Kyoto climate agreement, including subsequent definition of a developing country role, suggests that meaningful program implementation steps could not be up and running with confidence any time soon after a Kyoto agreement. There has been a great deal of focus on the beginning of such a so-called budget period.

In our view, the beginning of the budget period is not as important as the end of the budget period, i.e., the point at which the principle of "binding commitment" actually has the potential to impose penalty or sanction. In light of the uncertainties stated above, ratification, implementation, developing country role, and some level of experience with the implementation process, we believe that it would be inappropriate to end the first binding budget period before the year 2020. This timeframe will allow industry to develop its programs, and gain confidence in their performance.

ICCP also believes this timeframe is consistent with its previous position that policies at the outset of this effort must take into account a reasonable period for capital stock turnover. This will provide a period for industry to "ramp up" its climate change responses.

If the budget period is to be adopted, we believe that it should be long enough to encompass weather and economic cycles, but not so long as to present an impossible horizon to provide both industry and policymakers with some certainty. Therefore, it appears that a 10-year budget period is better than a 3- or 5-year period.

TECHNOLOGY ASSESSMENT

Although not specifically included as part of the current protocol proposals, ICCP continues to believe that the FCCC must be grounded in sound scientific and tech-

nological assessment processes. This function, as currently served primarily through the Intergovernmental Panel on Climate Change (IPCC), is inadequate.

The IPCC is currently considering restructuring proposals including the adoption of working group outlines that incorporate an effective role for private sector expert participation. We encourage support for these proposals.

Finally, it is also important that we de-politicize the IPCC process to the maximum extent possible. Its credibility can be sustained only if it is truly seen to be the work of scientific and technical experts, and not subject to the whims of the diplomatic and political process or other special interests.

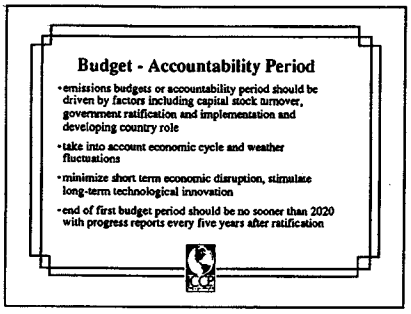
TRADING, BANKING AND JOINT IMPLEMENTATION (JI)

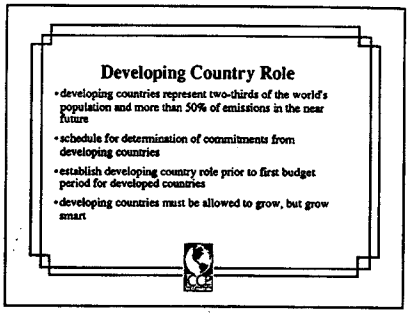
Most available economic analysis continues to indicate that flexibility through emissions trading, banking of emission credits, and joint implementation policies can help to maximize greenhouse gas emission reductions most cost-effectively. ICCP is fully supportive of such mechanisms as part of any agreement in Kyoto and beyond.

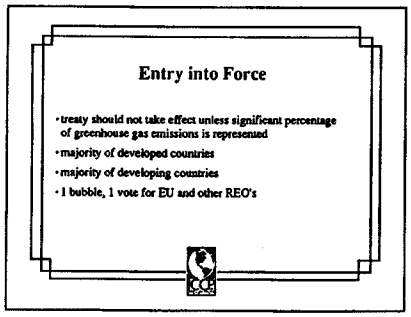
We believe it to be imperative that such principles be included in the first agreement and not be left to some future negotiations. We also believe it is important that these provision not be relegated to some pilot project with final decisions to be made at some future date.

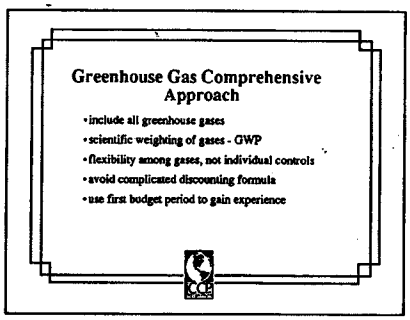
Finally, it appears that flexibility is a positive inducement to ensure maximum compliance. It also would allow us to avoid the use of trade restrictions or trade sanctions as an enforcement mechanism in the treaty.

ICCP Key Issues for Negotiating an International Climate Change Treaty

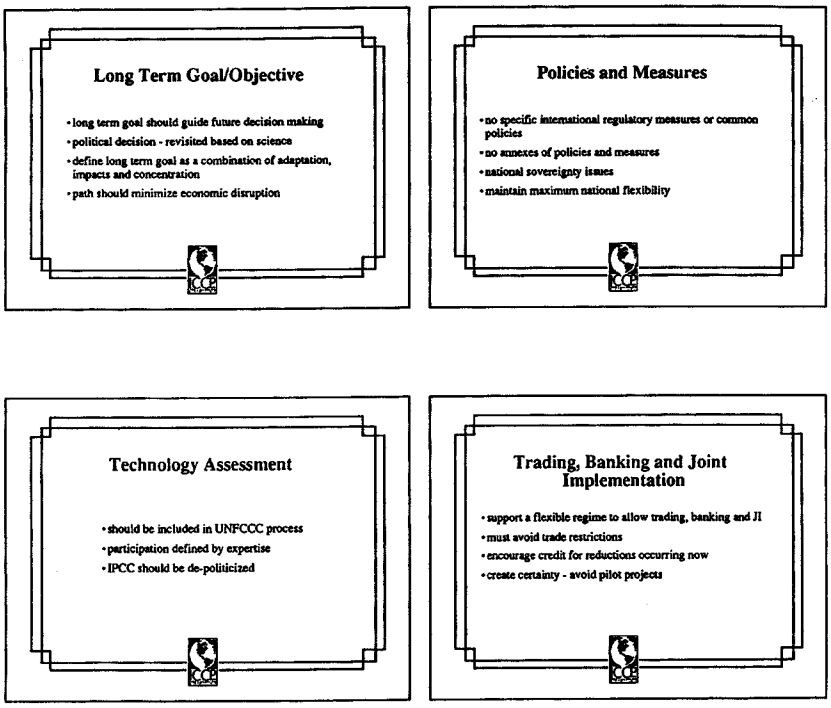








ICCP Key Issues for Negotiating an International Climate Change Treaty



STATEMENT OF WILLIAM F. O'KEEFE, CHAIRMAN, GLOBAL CLIMATE COALITION

Mr. Chairman and members of the committee, as chairman of the Global Climate Coalition (GCC), I appreciate the opportunity to testify before you on global climate negotiations. The GCC is the leading representative of business and industry on this issue with members that encompass manufacturing; agriculture; small and large businesses; air, rail and barge transportation companies; domestic and international vehicle manufacturers; oil, coal, natural gas and other natural resource companies; municipal, co-op, investor-owned and independent electric utilities; cement; iron and steel; forest and paper; and numerous producers of chemicals, plastics and other industrial and consumer products.

On behalf of this broad membership—the backbone of the U.S. economy—I would like to take this opportunity to set the record straight on five points that are key to the current public debate on climate change. First, the science is *not* "clear and compelling" as President Clinton claimed July 3 in his speech to the United Nations General Assembly, Special Session on Environment and Development. Instead, scientific uncertainties abound; enhanced global warming is still a hypothesis. Second, statements on scientific uncertainties by members of the GCC are consistent with those expressed in the May 16 issue of the respected journal *Science* [attached]. Advocates of precipitous curbs on greenhouse gas emissions are the ones who are unjustifiably representing climate science in promoting a rush to judgment. Third, curbs on greenhouse gas emissions—which mean suppressing energy use—will *not* be cheap and relatively painless as some advocates encourage Americans to believe. Instead, curbs would be brutally expensive in terms of lost income, lost jobs and lost U.S. competitiveness on world markets. Fourth, business does *not* oppose action as evidenced by its widespread participation in the Administration's voluntary Climate Action programs. We support action that recognizes the state of knowledge, the extent of uncertainty, and balances the need for preserving robust economic growth with the requirement for a cleaner environment. Fifth, the climate issue does *not* represent a crisis requiring precipitous and dramatic actions to prevent an imminent ecological catastrophe.

PRECIPITOUS ACTION ON CLIMATE CHANGE SERVES AN ANTI-INDUSTRY AGENDA

Claims of imminent catastrophe are designed to create a crisis atmosphere helpful in promoting other agendas. This strategy is routinely used to advance ill-advised policies—the saccharin scare in 1977, predictions in the 1970's of famine and the exhaustion of natural resources, the predicted cancer epidemic in the 1980's, and the Alar, EDB and electromagnetic scares to name only a few.[1]

When these scares proved to be unfounded, the quest continued to find the *ultimate* environmental problem that *will* require wholesale, radical change in American lifestyles.[2] The late Professor Aaron Wildavsky wrote that "warming (and warming alone) . . . is capable of realizing the environmentalist's dream of an egalitarian society based on rejection of economic growth in favor of a smaller population's eating lower on the food chain, consuming a lot less, and sharing a much lower level of resources more equally."[3] MIT Professor Richard Lindzen has added that "the great threat of warming fits in with a great variety of preexisting agendas—some legitimate, some less so: energy efficiency, reduced dependence on Middle Eastern oil, dissatisfaction with industrial society (neopastoralism), international competition, governmental desires for enhanced revenues (carbon taxes), and bureaucratic desires for enhanced power."[4]

And so it is that climate change underpins the claims:

- That the automobile is a greater threat than any enemy we will ever face.
- That suburbia should be phased out.[5]

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[1] For a more complete listing of scares, see: Adam J. Lieberman, *Facts Versus Fears: A Review of the 20 Greatest Unfounded Health Scares of Recent Times*, prepared for the American Council on Science and Health, May 1997.

[2] For instance, the president of the World Resources Institute wrote: "Climate change isn't just any environmental issue. It's bigger . . . *it's tied to almost every facet of contemporary economic life.* How we travel, manufacture and ship goods, build buildings, farm, and spend our leisure time all influences the tempo of climate change." [emphasis in original] See: Gus Speth, forward to *The Greenhouse Trap (World Resources Institute, 1990).*

[3] Aaron Wildavsky, "Global Warming as a Means Of Achieving an Egalitarian Society: An Introduction," introduction to Robert C. Balling, Jr., The Heated Debate (1992), xv.

[4] Richard S. Lindzen, "Global Warming: The Origin and Nature of the Alleged Scientific Consensus," Regulation, Vol. 15, No 2, (Spring 1992).

[5] Worldwatch Institute, *Beyond the Petroleum Age: Designing a Solar Economy* (December 1990), 48.

• That human numbers must be drastically reduced.[6]

Obviously, evidence that climate change may not be an imminent catastrophe undermines such visions of America in the 21st Century. Indeed, unwavering allegiance to such agendas may explain why advocates of precipitous action deny with vehemence the logical implications of obvious scientific uncertainties.

True concern for the economic and environmental well-being of people in this and other countries would surely lead negotiators to balance their policy prescriptions with the state of scientific evidence. After all, carbon dioxide (CO_2) is not a pollutant but a natural element necessary for survival, with man-made emissions directly related to prosperity and economic progress. Curbing those emissions unnecessarily would mean fewer jobs and less income—and therefore less money for other health and environmental protection measures. A less prosperous United States means a nation less able to promote technological development which is essential to environmental progress and to our continued ability to adapt in a changing world.

THE SCIENCE IS NOT SETTLED

The hearings of this committee a week ago—and those of the Senate Subcommittee on International Economic Policy, Export and Trade Promotion chaired by Senator Hagel in June—have put a much-needed public spotlight on the compelling scientific uncertainties that should permeate every climate change discussion and negotiation. Climate scientists and modelers simply do not know enough about possible human impacts on the global climate system to justify taking near-term actions being considered by international negotiators that would require us to suppress energy use by at least 25 percent in little over a decade.

That opinion is shared by scientists who participated in the Intergovernmental Panel on Climate Change (IPCC) and wrote the 1995 *Second Assessment Report*, along with many other members of the scientific community. That report does state that "the balance of evidence suggests a discernible human influence on global climate" and the Administration repeatedly quotes that sentiment—out of context—in its statements that the "science is settled." The May 16 issue of the journal Science pointed out that Dr. Benjamin Santer, a lead IPCC author, warned against such over-simplification when he stated that, "It's unfortunate that many people read the media hype before they read the [IPCC] chapter [on greenhouse warming] . . . We say quite clearly that few scientists would say that the attribution issue was a done deal." That same *Science* article also notes that "[s]ome scientists assert that developments since the IPCC completed its report have, if anything, magnified the uncertainties," and quotes a noted scientist as saying, "There really isn't a persuasive case being made" for detection of greenhouse warming. At the article's end, the author refers to a climatologist and IPCC contributor who concluded that "while researchers are firming up the science, policy-makers could inaugurate 'some cautious things' to moderate any warming."

Unquestionably, the concentration of CO_2 in the atmosphere has increased. It has gone from about 280 parts per million two centuries ago to about 360 parts per million today. It is generally agreed that this increase is due to human activity, especially combustion of fossil fuels. CO_2 like several other gases in the atmosphere, especially water vapor, traps heat. Without this greenhouse effect, the average global temperature would be about zero degrees and life as we know it would not be possible. In theory, if CO_2 is increasing, more heat might get trapped and the temperature might rise.

But theory is not fact until subjected to the acid test of scientific rigor to confirm or reject it. To date, no confirming evidence has withstood tough scrutiny—as the May 16 *Science* article explains. While it is a fact that there has been some warming over the past century, it is within the range of normal variability. Furthermore, most of it occurred before 1940, which was before any significant increase in CO_2 emissions. In particular, over the past 20 years, when high-quality satellite measurements of temperature began, no warming has been observed; and, in fact, there has been a slight downward trend.

Moreover, Dr. Bert Bolin, the chairman of the IPCC, has repeatedly said science has not established a link between human greenhouse gas emissions and particular severe weather events. Yet, Vice President Gore and other Administration officials made such an overstatement when they associated the flooding in North Dakota earlier this year with global warming. President Clinton made a similar overstatement when he said on June 30 in New York City that greenhouse gases have "led to the most disruptive weather patterns anybody can remember over the last 4 or 5 years." Members of the GCC and of the business community are only being accu-

[6] Bill McKibben, *The End of Nature* (1989), 191–192.

rate when they point out that such claims go beyond what can be supported by climate science.

EXEMPTING THE DEVELOPING COUNTRIES GUARANTEES FAILURE

Dr. Bolin has also cautioned against expecting global temperature benefits from emission reductions by developed countries alone. Yet, the Berlin Mandate agreed to by international negotiators in 1995 exempts developing countries from any new commitments to curb emissions. Dr. Bolin, during his February 25, 1997 presentation in Bonn to international negotiators, said that the proposals applicable only to the industrialized nations "would not be detectable on projected temperature increases."

The 2,000 economists who signed a petition on climate change—and the 65 U.S. Senators who have signed Senate Resolution 98—emphasize that all countries must participate in any program to address "global" emissions. China, India and other developing countries will account for most of the future growth in carbon dioxide (CO_2) emissions in the next century but will be exempt from any meaningful treaty obligations. This will create powerful incentives to attract manufacturing investments and the jobs they create from the industrialized countries—and also create powerful economic and political constituencies for *never* curbing emissions. As Representative John Dingell asked rhetorically in his testimony of June 19 before the Senate Subcommittee on International Economic Policy, Export and Trade Promotion: "Does anyone seriously believe China, or any other country for that matter, will act on altruistic motives?" Without the active involvement of developing countries, the growth in global CO_2 emissions will not be reduced in any meaningful way.

THE ECONOMIC COSTS WOULD BE HIGH

The Administration suggests that curbing energy use will impose little economic sacrifice. Everett M. Ehrlich, former undersecretary of commerce for economic affairs, wrote in *The Washington Post* of June 15, 1997 that "the economic literature suggests that we could roll back our CO_2 emissions to their 1990 levels by 2010 for the equivalent of a 25 cent gas tax. It's not free, but it's not the end of the world." Few consumers would share this benign view of such a hike in their energy bills. Some authors of the IPCC report even suggest that curbing greenhouse gas emissions could be free—the environmental equivalent of a free lunch—or even be economically beneficial![7]

In fact, however, every credible, independent economic analysis confirms what common sense suggests: a substantial curb on the use of a key economic resource will impose substantial costs. From an Administration draft analysis circulated last May, one could reasonably conclude that U.S. negotiators want to cut CO_2 emissions back to 1990 levels by sometime around 2010, and hold them there. This would require more than a 25 percent reduction in projected fossil fuel use. The Administration is placing its blind faith in unidentified technological breakthroughs and an unproven—and probably unworkable—trading scheme to counterbalance the economic damage of self-imposed energy rationing.

However, economic studies more realistic about the probable contributions of existing and new technologies paint a more sobering picture. Studies by Charles River Associates, DRI, and the U.S. Energy Information Administration indicate that energy taxes of $125 to $200 per metric ton of carbon would be needed to return emissions to 1990 levels by 2010 ($200 per ton is equivalent to an increase in the excise tax on gasoline of about 60 cents a gallon). The annual impact of a tax this size includes the following losses:

- $100 billion to $275 billion in gross domestic product (GDP).
- $200,000 to $500,000 U.S. jobs.
- $65 billion to $100 billion in fixed business investment.
- $50 billion to $110 billion in consumer purchases.

THE CLINTON ADMINISTRATION HAS BEEN SLOW TO RELEASE ITS ECONOMIC ANALYSIS

DOE released on July 11, 1997 a study contracted with Argonne National Laboratory early in 1996 to investigate "the potential effects (which may be either beneficial or adverse) on energy-intensive industries in the United States of alternative

[7] These authors wrote: "Despite significant differences in views, there is agreement that energy efficiency gains of perhaps 10 to 30% over baseline trends over the next two or three decades can be realized at negative or zero net cost (negative net cost means an economic benefit)." See: International Panel on "Climate Change, *Climate Change 1995: Economic and Social Dimensions of Climate Change*." Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change (1996), 16.

scenarios for changes in world patterns of industrial energy prices that might result from new climate commitments." Six industries were selected and the study results show that the impact on each industry would range from "significantly adverse" to "devastating" and produce little, if any, environmental benefit.[8]

The U.S. Department of Energy (DOE) has attempted to put these results in a favorable light by claiming that the study examines energy price scenarios based on *other* countries' proposals "of large hypothetical energy price increases" rather than the "Administration's basic approach." However, the Administration has not explained how its own goals for curbing emissions could possibly avoid either high energy prices or highly restrictive regulatory curbs on energy use. At the very least, the DOE's claim that the Argonne study results apply only to the climate change proposals of other countries is an open admission that this study lacks a direct analysis of the Administration's own proposals. Hence, DOE's claim that the study "confirms the wisdom of the Administration's basic approach to climate change" is without foundation.

The delay in releasing this study and the release two days ago by the Administration of its long-promised analysis and assessment of its own post-2000 climate change proposals raises questions about its negotiating objectives.

In March 1995, as the Berlin Mandate began to take shape, President Clinton characterized U.S. objectives this way in a letter to Representative John Dingell:

> "We have said this process must include thoughtful analysis and reflect the fact that global problems require global solutions. Furthermore, I assure you the U.S. delegation will not accept any outcome or agree to any process that adversely affects the United States and its industrial competitiveness."

DOE and the Environmental Protection Agency (EPA) jointly held a workshop in Springfield, Virginia to unveil the Administration's initial analysis. At a June 19, 1996 hearing before the House Commerce Committee, the DOE's Acting Assistant Secretary for Policy—Marc Chupka—testified that the "U.S. strongly believes that analysis and assessment is central to the development of further commitments by Annex I Parties and to the furtherance of existing commitments of other parties to the Framework Convention on Climate Change." When it was announced last summer that Dr. Everett Ehrlich would assume the role of directing and coordinating this analytic effort, he assured everyone that the results would be available this past January. Over the next several months, Under Secretary of State Tim Wirth repeatedly stated that the Administration's analysis would be released soon. This did not occur and yet negotiations proceeded.

This state of affairs led Representative Dingell in his Senate testimony of June 19, 1997 to ask:

> "Why are we [proceeding with negotiations] before we have the most basic information about how climate change policies will affect our economy? In short, has the Administration bothered to do its homework? We were supposed to have the vaunted analysis and assessment of the impact of climate change policies on the U.S. economy by the end of last year. It has not been completed yet, despite repeated promises to Congress and industry that it would be available before important policy decisions are made. But the State Department formally proposed a cap-and-trade negotiating position in January. In short, the analysis is self-evidently too late to inform the process, and likely will be used to justify what the Administration has already decided to do. Just as clearly, public participation and comment on the analysis and assessment is irrelevant."

Representative Dingell's remarks were insightful. Only two days ago did the Administration release a draft copy of its baseline economic analysis. While the GCC has not had time to examine this document thoroughly—and we would ask the committee for the opportunity to submit comments later—it is clear that the Administration still has not provided its *assessment* of specific policies now under consideration. It also has not explained how those policies would be implemented domestically and internationally nor has it quantified the impact of these policies on the U.S. economy, labor, industry and trade.

This slow and partial release of the Administration's analysis and assessment has meant that the United States Senate has so far been unable to fulfill its Constitutional responsibility of "Advice and Consent." Senate Resolution 98, introduced by Senators Byrd and Hagel—and now co-sponsored by 65 Senators reflects growing frustration with the Administration's failure to consult and alarm over the con-

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[8] The six industries studied were: aluminum; chemicals and allied products; petroleum refining; cement; paper and allied products; and steel.

sequences for the U.S. economy that will result from the current negotiating strategy.

THE GCC SUPPORTS APPROPRIATE ACTION

In spite of major scientific uncertainties, inadequacies in climate models and the doubt that any enhanced warming will soon occur, it would be imprudent to presume "no problem." Global warming could have serious consequences should nations make wrong choices in *either* direction.

Therefore, a proper framing of the problem recognizes uncertainty—as pointed out by the petition signed by 2,600 economists. The Administration frames climate change as devoid of significant uncertainty—an approach that is clearly flawed.

The basic structure for decision-making under conditions of significant uncertainty is relatively simple even though the global climate issue itself is complex. The first decision rule is to be slow rather than quick to commit to a single course of action. This is especially important when the costs of immediate action are known to be high—perhaps equal to our Nation's current total annual environmental expenditures—but the many scientific uncertainties prevent any reliable estimate of the environmental benefits (if any) from that action. In the case of global warming, we have time to address these uncertainties. Nothing we do in the next 20 years will have any appreciable impact on the world's average temperature in 2050 or 2100.

This fact is absolutely crucial, because costs are exceedingly sensitive to timing. Many capital investments, including those in the energy and automobile industries, are long term. If change can be deferred until current equipment reaches the end of its useful life, and until more efficient devices are on-line, costs can be substantially less. Over the past 22 years, new technologies have enabled us to reduce energy intensity per dollar of gross domestic product by about 32 percent. This progress should continue. Analysis by the Electric Power Research Institute and the Stanford Energy Modeling Forum concludes that an orderly, long-term strategy for achieving a scientifically justified CO_2 objective would cost only one-fifth as much as a program that requires near-term cuts.[9]

This leads to the second decision-making rule: invest in information to reduce the uncertainties and to better understand the implications of alternative courses of action. Indeed, the money already spent on improving climate models has increased our understanding of the climate system enormously with no indications yet that we have reached the point of diminishing returns in improving scientific knowledge and climate models.

Furthermore, as climate models have improved they have—so far—suggested that much of the 1°F increase in average global temperature over the past 130 years is due to natural variability and that any future warming is likely to be much less than earlier models have predicted. For instance, when the British Meteorological Office recently improved its modeling of the effects of clouds and precipitation, the model's response to a doubling of CO_2 emissions was a *decline* in warming from 5.2 Celsius degrees to 1.9 degrees. The first results from the new climate model at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado suggest—according to the May 16 article in *Science*—that "future greenhouse warming may be milder than some other models have suggested—and could take decades to reveal itself."

With improved information indicating that the problem may be less—rather than more—severe than originally thought, it seems only sensible to continue improving scientific knowledge before committing to expensive policies predicated on earlier estimates, as the Administration appears determined to do. Although assessments of potential future impacts have moderated over the past few years, the Administration's policy has shifted from support of voluntary programs to legally-binding commitments.

The third rule for decision-making under uncertainty is called "no or low regrets." Look for actions that will produce benefits under any set of circumstances. The GCC has developed a list of emission-reducing actions that would be worthwhile even if the threat of global warming turns out to be another wildly exaggerated environmental scare.

The business community has shared these steps with the Administration which are based on these points:

- Encourage an economic turnover of the capital stock.
- Focus investment in research to narrow the range of scientific uncertainties.
- Invest in the development of new technologies.

[9] EPRI Journal, Nov./Dec. 1995.

• Expedite diffusion of new technologies in developing countries.
• Facilitate the investment of U.S. private capital in countries with high emissions levels.
• Continue promoting voluntary programs for reducing U.S. emissions.

These points establish that GCC members support an action-oriented policy on climate change.

The fourth decision rule is to consider alternatives. Only two decades ago, global cooling was the dominant concern. It is also possible that some warming will occur but not be harmful—or that developing adaptations to warming will greatly mitigate any harm. Sound policies must allow for these possibilities, and not be based on a single point estimate.

SUMMARY AND CONCLUSION

Many uncertainties about the climate system, and the current and future impact of human activities on it, have been well documented. Business has played a constructive role by drawing attention to these uncertainties and the serious ramifications they pose for the Administration's negotiating strategy.

Business agrees that action *should* be taken but rejects an unjustified rush to judgment. The major difference between the business community and the Clinton Administration is over approach, not the need for action. We support what can be called "Lewis and Clark" planning, after the famous explorers who successfully managed enormous uncertainty by gathering new information, taking a limited number of steps, reassessing and then repeating the process. In 1803, Lewis and Clark could not plan a detailed water route to the Pacific—President Jefferson's main goal. No one knew that the Rocky Mountains were in the way. Lewis and Clark were successful because they respected the limits of knowledge, anticipated surprises and recognized the need to adapt.

The Clinton Administration supports an approach that discounts uncertainty. Minimal uncertainty allows detailed planning comparable to an extended itinerary what can be called "Cooke's Tour planning" after the famous travel agency. The conditions for this type of policy planning do not exist, and a Kyoto agreement that presumes they do will be playing "Russian Roulette" with our economy.

INTERNATIONAL CLIMATE CHANGE PARTNERSHIP

ICCP 1997 MEMBERSHIP LIST

- 3M Company
- AB Electrolux/White Consolidated Industries
- Aerospace Industries Association
- Air Conditioning and Refrigeration Institute
- Alliance for Responsible Atmospheric Policy
- Alliance for Responsible Environmental Alternatives - Canada
- AlliedSignal
- Association of Home Appliance Manufacturers
- AT&T
- Boeing
- BP America/BP Exploration
- Carrier
- Celotex/Center for Applied Engineering
- Dow Chemical
- Dresser Industries
- Dupont
- Eastman Kodak
- Elf Atochem
- Enron
- European Chemical Industry Council (CEFIC) - European Fluorocarbon Technical Committee (EFCTC) Sector
- FMC Corporation
- General Electric
- ICI Klea
- Japan Fluorocarbon Manufacturers Association
- Japan Industrial Conference for Ozone Layer Protection
- Lennox International
- Polyisocyanurate Insulation Manufacturers Association
- Trane
- United Technologies
- Whirlpool Corporation
- Wisconsin Electric
- York International

Greenhouse Forecasting Still Cloudy

An international panel has suggested that global warming has arrived, but many scientists say it will be a decade before computer models can confidently link the warming to human activities

The headlines a year and a half ago positively brimmed with assurance: "Global Warming: No Longer in Doubt," "Man Adversely Affecting Climate, Experts Conclude," "Experts Agree Humans Have 'Discernible' Effect on Climate," "Climate Panel Is Confident of Man's Link to Warming." The official summary statement of the UN-sponsored Intergovernmental Panel on Climate Change (IPCC) report that had prompted the headlines seemed reasonably confident, too: "... the balance of evidence suggests that there is a discernible human influence on global climate." But as negotiators prepare to gather in Bonn in July to discuss a climate treaty that could require nations to adopt expensive policies for limiting their emissions of carbon dioxide and other greenhouse gases, many climate experts caution that it is not at all clear yet that human activities have begun to warm the planet—or how bad greenhouse warming will be when it arrives.

NCAR

Rough approximation. Models can't reproduce clouds, but they incorporate some cloud effects, including those of water (white) in the atmosphere, seen in the above model output.

What had inspired the media excitement was the IPCC's conclusion that the half-degree rise in global temperature since the late 19th century may bear a "fingerprint" of human activity. The patchy distribution of the warming around the globe looks much like the distinctive pattern expected if the heat-trapping gases being poured into the atmosphere were beginning to warm the planet, the report said. But IPCC scientists now say that neither the public nor many scientists appreciate how many if's, and's, and but's peppered the report. "It's unfortunate that many people read the media hype before they read the [IPCC] chapter" on the detection of greenhouse warming, says climate modeler Benjamin Santer of Lawrence Livermore National Laboratory in Livermore, California, the lead author of the chapter. "I think the caveats are there. We say quite clearly that few scientists would say the attribution issue was a done deal."

Santer and his IPCC colleagues' overriding reason for stressing the caveats is their understanding of the uncertainty inherent in computer climate modeling. The models are key to detecting the arrival of global warming, because they enable researchers to predict how the planet's climate should respond to increasing levels of greenhouse gases. And while predicting climate has always been an uncertain business, some scientists assert that developments since the IPCC completed its report have, if anything, magnified the uncertainties. "Global warming is definitely a threat as greenhouse-gas levels increase," says climate modeler David Rind of NASA's Goddard Institute for Space Studies (GISS) in New York City, "but I myself am not convinced that we have [gained] greater confidence" in recent years in our predictions of greenhouse warming. Says one senior climate modeler who prefers not to enter the fray publicly: "The more you learn, the more you understand that you don't understand very much." Indeed, most modelers now agree that the climate models will not be able to link greenhouse warming unambiguously to human actions for a decade or more.

The effort to simulate climate in a computer faces two kinds of obstacles: lack of computer power and a still very incomplete picture of how real-world climate works. The climate forecasters' basic strategy is to build a mathematical model that recreates global climate processes as closely as possible, let the model run, and then test it by comparing the results to the historical climate record. But even with today's powerful supercomputers, that is a daunting challenge, says modeler Michael Schlesinger of the University of Illinois, Urbana-Champaign: "In the climate system, there are 14 orders of magnitude of scale, from the planetary scale—which is 40 million meters—down to the scale of one of the little aerosol particles on which water vapor can change phase to a liquid [cloud particle]—which is a fraction of a millionth of a millimeter."

Of these 14 orders of magnitude, notes Schlesinger, researchers are able to include in their models only the two largest, the planetary scale and the scale of weather disturbances: "To go to the third scale—which is [that of thunderstorms] down around 50-kilometers resolution—we need a computer a thousand times faster, a teraflops machine that maybe we'll have in 5 years." And including the smallest scales, he says, would require 10^{36} to 10^{37} more computer power. "So we're kind of stuck."

To get unstuck, modelers "parameterize" smaller scale processes known to affect climate, from the formation of clouds to the movement of ocean eddies. Because they can't model, say, every last cloud over North America, modelers specify the temperatures and humidities that will spawn different types of clouds. If those conditions hold within a single grid box—the horizontal square that represents the model's finest level of detail—the computer counts the entire area as cloudy. But as modelers point out, the grid used in today's models—typically a 300-kilometer square—is still very coarse. One over the state of Oregon, for instance, would take in the coastal ocean, the low coast ranges, the Willamette Valley, the high Cascades, and the desert of the Great Basin.

Having the computer power to incorporate into the models a more detailed picture of clouds wouldn't eliminate uncertainties, however, because researchers are still hotly debating the overall impact of clouds on future climate. In today's climate, the net effect of clouds is to cool the planet—although they trap some heat, they block even more by reflecting sunlight back into space. How that balance would change under greenhouse warming, no one knows. A few years ago, a

Model Gets It Right—Without Fudge Factors

Climate modelers have been "cheating" for so long it's almost become respectable. The problem has been that no computer model could reliably simulate the present climate. Even the best simulations of the behavior of the atmosphere, ocean, sea ice, and land surface drift off into a climate quite unlike today's as they run for centuries. So climate modelers have gotten in the habit of fiddling with fudge factors, so-called "flux adjustments," until the model gets it right.

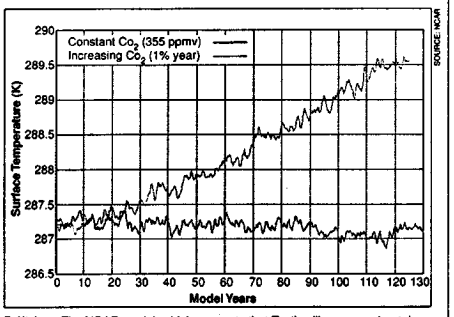
No one liked this practice (*Science*, 9 September 1994, p. 1528). "If you can't simulate the present without arbitrary adjustments, you have to worry," says meteorologist and modeler David Randall of Colorado State University (CSU) in Fort Collins. But now there's a promising alternative. Thirty researchers at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, have developed the first complete model that can simulate the present climate as well as other models do, but without flux adjustments. The new NCAR model, says Randall, "is an important step toward removing some of the uneasiness people have about trusting these models to make predictions of future climate" (see main text).

The NCAR modelers built a host of refinements into their new Climate System Model (CSM). But the key development, says CSM co-chair Byron Boville, was finding a better way to incorporate the effects of ocean eddies, swirling pools of water up to a couple of hundred kilometers across that spin off strong currents. Climate researchers have long known that the eddies, like atmospheric storms, help shape climate by moving heat around the planet. But modelers have had a tough time incorporating them into their simulations because they are too small to show up on the current models' coarse geographic grid. The CSM doesn't have a finer mesh, but it does include a new "parameterization" that passes the effects of these unseen eddies onto larger model scales, using a more realistic means of mixing heat through the ocean than any earlier model did, says Boville.

Even when run for 300 model "years," the CSM doesn't drift away from a reasonably realistic climate, says NCAR's Climate and Global Dynamics director Maurice Blackmon. "Being able to do this without flux corrections gives you more credibility," he says. "For better or worse, we're not biasing the results as was necessary before."

The first results from this still vastly simplified model imply that future greenhouse warming may be milder than some other models have suggested—and could take decades to reveal itself. Doubling atmospheric carbon dioxide concentrations in the model raised the global temperature 2 degrees Celsius, which puts the model's sensitivity to greenhouse gases near the low end of current estimates. Based on an array of different models and other considerations, the UN-sponsored Intergovernmental Panel on Climate Change estimated in 1995 that a carbon dioxide doubling could raise global temperatures by as much as 4.5°C; their best guess was 2.5°C.

A 300-year run without any increase in greenhouse gases produced slow, natural variations in global temperature of about 0.5°C. If the real climate behaves the same way, "two-thirds to three-quarters of the [temperature variations of the] last 130 years can be explained as natural variation," says Blackmon. That would make the detection of a modest-size greenhouse warming all the more difficult.



Drift-free. The NCAR model, which suggests that Earth will warm moderately (red), can reliably simulate present climate (blue).

The CSM is available on the Internet, but Blackmon warns that if you want to check out future climate scenarios, you'll "need the biggest supercomputer you can get." Indeed, even NCAR researchers haven't been able to experiment with the model on as large a computer as they would like. While their purchase of an NEC SX4 computer is tied up in a trade dispute with Japan (*Science*, 30 August 1996, p. 1177), they are making do with a leased Cray C-90 with perhaps 20% of the speed of the SX4. That worries some modelers. Americans have "been among the leaders of the field from the beginning," says CSU's Randall, but "if we can't get access to the most powerful machines, we are going to be left behind."

–R.A.K.

leading climate model—developed at the British Meteorological Office's Hadley Center for Climate Prediction and Research, in Bracknell—predicted that an Earth with twice the preindustrial level of carbon dioxide would warm by a devastating 5.2 degrees Celsius. Then Hadley Center modelers, led by John Mitchell, made two improvements to the model's clouds—how fast precipitation fell out of different cloud types and how sunlight and radiant heat interacted with clouds. The model's response to a carbon dioxide doubling dropped from 5.2°C to a more modest 1.9°C.

Other models of the time also had a wide range of sensitivities to carbon dioxide, largely due to differences in the way their clouds behaved. That range of sensitivity has since narrowed, says modeler and cloud specialist Robert Cess of the State University of New York, Stony Brook, but "the [models] may be agreeing now simply because they're all tending to do the same thing wrong. It's not clear to me that we have clouds right by any stretch of the imagination."

Nor are clouds the only question mark in researchers' picture of how climate works. Modelers saw for the first time the fingerprint of global warming when they folded an additional process into the models: the effect of pollutant hazes on climate. Wind-blown soil and dust, particles from the combustion of fossil fuels, and ash and soot from

agricultural burning all reflect sunlight—shading and cooling the surface beneath them. Including this aerosol effect in four independent climate models at three centers—Livermore, the Hadley Center, and the Max Planck Institute for Meteorology (MPI) in Hamburg, Germany—produced geographic patterns of temperature changes that resembled those observed in the real world over the past few decades, such as the greater warming of land than ocean.

Fingerprinting work since then has only strengthened the confidence of IPCC's more confident scientists that greenhouse warming has arrived. "I've worked with the models enough to know they're not perfect, but we keep getting the same answer," says Tim P. Barnett, a climatologist at the Scripps Institution of Oceanography in La Jolla, California, and a co-author of the IPCC chapter. Another climatologist and IPCC contributor, Gerald North of Texas A&M University in College Station, is similarly heartened. "I'm pretty optimistic about climate modeling. ... I don't know anybody doing [fingerprinting] who is not finding the same result."

Crucial component. Thunderstorms like the one above help to shape climate by lofting heat and moisture.

But the assumptions about how hazes affect climate may have taken a hit recently from climatologist and modeler James Hansen of NASA's GISS—the man who told Congress in 1988 that he believed "with a high degree of confidence" that greenhouse warming had arrived. In a recent paper, Hansen and his GISS colleagues pointed out that recent measurements suggest that aerosols don't just cool; they also warm the atmosphere by absorbing sunlight. The net effect of this reflection and absorption, Hansen estimates, would be small—too small to have much effect on temperature.

Hansen and his colleagues conclude that aerosols probably do have a large effect on climate, but indirectly, through clouds. By increasing the number of droplets in a cloud, aerosols can amplify the reflectivity of clouds, and thus may have an overall cooling effect on the atmosphere. If true, this would greatly complicate the modelers' work, because meteorologists are only just starting to understand how efficiently particles of different sizes and compositions modify clouds. "I used to think of clouds as the Gordian knot of the problem," says cloud specialist V. Ramanathan of Scripps. "Now I think it's the aerosols. We are arguing about everything."

And the complications don't stop with the multiplication of aerosol effects, according to Christopher Folland of the Hadley Center. Folland and his colleagues have been trying to sort out what was behind the intermittent warming of recent decades, which in the third quarter of the century was more rapid in the Southern than Northern Hemisphere. Earlier work by Santer and a dozen other colleagues showed an increasing resemblance between the observed pattern of warming through 1987, the end of their temperature record, and the results of a model run that incorporated aerosol effects. The researchers suggested that the North's more abundant pollutant aerosols could have been moderating the warming there from greenhouse gases. But when Folland compared the results of his model run with a longer, more recent temperature record, the resemblance that had been building into the 1980s faded by the early 1990s. Contrarian Patrick Michaels of the University of Virginia, Charlottesville, also has pointed out this trend.

The Hadley model suggests that "there appears to be more than one reason" for the variations, says Folland. The waning of aerosols as pollution controls took effect probably helped the North catch up, he says, but so did natural shifts in atmospheric circulation that tended to warm the continents (*Science*, 7 February, p. 754). Most provocatively, Folland and his colleagues are suggesting that a shift in North Atlantic Ocean circulation that has tended to warm the region also has contributed. "There's no doubt," says Santer, "that multiple natural and anthropogenic factors can contribute, and probably have, to the interhemispheric temperature contrast. ... We've learned something about detection."

All of which only adds to the skepticism of scientists who might be called the "silent doubters": meteorologists and climate modelers who rarely give voice to their concerns and may not have participated even peripherally in the IPCC. "There really isn't a persuasive case being made" for detection of greenhouse warming, argues Brian Farrell of Harvard University, who runs models to understand climate change in the geologic past. Farrell has no quarrel with the IPCC chapter on detecting greenhouse warming, but he says the executive summary did not "convey the real uncertainties the science has." He further contends that if IPCC scientists had had real confidence in their assertion that global warming had arrived, they would have stated with more precision how sensitive the climate system is to greenhouse gases. But the IPCC left the estimate of the warming from a doubling of carbon dioxide at 1.5°C to 4.5°C, where it has been for 20 years. "That's an admission that the error bars are as big as the signal," says Farrell.

Climate modeler Max Suarez of NASA's Goddard Space Flight Center in Greenbelt, Maryland, agrees that it's "iffy" whether the match between models and temperature records is close enough to justify saying that greenhouse warming is already under way. "Especially if you're trying to explain the very small [temperature] change we've seen already," he says, "I certainly wouldn't trust the models to that level of detail yet."

Rather than dwelling on model imperfections, IPCC co-author Barnett emphasizes some of the things that current models are doing fairly well—simulating present and past climates and the changing seasons, predicting El Niño a year ahead, and producing good simulations of decades-long climate variations. But he agrees that too much confidence has been read into the IPCC summary statement. "The next 10 years will tell; we're going to have to wait that long to really see," he says. Klaus Hasselmann of the MPI also sees a need to wait. He and his colleagues "think we can see the [greenhouse warming] signal now with 97% confidence." But, as North notes, "all that assumes you knew what you were doing to start with" in building the models. Hasselmann has faith in his model but recognizes that his faith is not universally shared. "The signal is not so much above the noise that you can convince skeptics," he observes. "It will take another decade or so to work up out of the noise."

That's no excuse for complacency, many climate scientists say. Basic theory, this century's warming, and geologic climate records all suggest that increasing carbon dioxide will warm the planet. "I'd be surprised if that went away," says Suarez, as would most climate researchers. North suggests that while researchers are firming up the science, policy-makers could inaugurate "some cautious things" to moderate any warming. The last thing he and his colleagues want is a rash of headlines saying the threat is over.

–Richard A. Kerr

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August 13, 1997

The Honorable John H. Chafee
Chairman
Committee on Environment and Public Works
United States Senate
407 Hart Senate Office Building
Washington, D.C. 20510

Dear Senator Chafee:

Thank you for providing me the opportunity to testify on July 17 before the Senate Committee on Environment and Public Works. The Global Climate Coalition ("GCC") commends you and your fellow committee members for holding hearings on the international negotiations to amend the Framework Convention on Climate Change. These negotiations have an established objective to impose upon the developed countries of the world binding targets and timetables to reduce greenhouse gas emissions. As you stated during the hearing, the environmental, economic and trade implications of such commitments would be enormous for the United States. Indeed, the passage on July 25 of Senate Resolution 98, by an overwhelming vote of 95-0, reflects the Senate's intensified concern that the Administration's negotiating positions will not advance our national environmental or economic interests.

Attached are my responses to the questions posed in your July 30 letter. I would emphasize that in your opening statement at the Committee hearing on July 10 you explained that you are "convinced that the science on this matter has and will continue to evolve." The GCC shares that view and has endorsed policies for further scientific research, evaluation, and open dialogue concerning the many outstanding issues regarding climate behavior and change, and the impacts of potential change. While the Administration has recently emphasized its "outreach" efforts, and a more constructive dialogue with the business community has begun, recent statements by Interior Secretary Babbitt and Vice-President Gore have proven counterproductive. As explained more fully in my response to your first question, which is attached, these statements have branded the business community, and by implication anyone else who raises questions about scientific uncertainty, with charges of "unethical" and "Un-American" behavior. To say the least, remarks such as these are inaccurate and ill-timed and undermine good-faith efforts to promote an informed and honest dialogue on this important issue of public policy. The GCC appreciates your efforts, and those of your fellow committee members,

to elicit and evaluate the best available scientific and economic evidence to guide our decisionmaking. Surely that process can not accommodate zealous advocacy which goes so far as to indict the patriotism of those with whom one does not agree.

Again, thank you for the opportunity to testify on behalf of the GCC. If I can be of any assistance to you or the committee in the future regarding the issue of climate change, please do not hesitate to call.

Sincerely,

William F. O'Keefe
Chairman

RESPONSES BY WILLIAM F. O'KEEFE TO ADDITIONAL QUESTIONS FROM SENATOR CHAFEE

Question 1. Mr. O'Keefe, you say in your testimony that you support "appropriate action." You want to encourage economic turnover of capital stock, spur the development of new technologies, and expedite their diffusion in developing countries. You also want to "facilitate the investment of U.S. private capital in countries with *high emissions levels*."

I assume by that last point you mean that you are interested in spurring investment that reduces these high emissions, is that right? (If yes,) now why would you be interested in reducing these emissions?

Answer. As I responded at the hearing when asked if there is a climate change "problem", the GCC recognizes that there is a *risk* that deserves to be addressed. Until the uncertainty surrounding this issue is reduced by expanding our State of knowledge, we simply do not know whether there is a genuine and serious "problem." We do know that there is a very real risk that precipitous action will cause society's scarce resources to be wasted and our economic well being damaged. The *risk* of human-induced climate change warrants current efforts to ensure that we undertake emissions policies which are generally termed "no" or "low" regrets. Such a policy, which calibrates our national response to the still uncertain and evolving understanding of human impacts on the climate system, is what I meant when I urged "appropriate action" to reduce emissions. Such actions include promoting research leading to more energy-efficient technologies and their subsequent export to developing countries. The expanded use of current and future energy-efficient technologies in developing countries will contribute to their productivity improvements and economic strength and is therefore a desirable goal in itself. It also would limit GHG emissions growth in those countries and therefore diminish the risk associated with higher CO_2 concentration levels.

I would like to stress, however, that today there is an entirely legitimate scientific debate regarding the extent, if any, of human-induced climate change and of what the impacts of change might be—past, present, and future. Most regrettably, as the scientific community publicly acknowledges the uncertainty, and as warming predictions for the next century moderate substantially, the Administration has declared the debate to be over and attacked the patriotism and integrity of those who raise legitimate questions about their apocalyptic visions.

As your first hearing on July 11 amply demonstrated the utter lack of scientific consensus regarding human-induced climate change, I will not address that fact further. However, I would like to draw the committee's attention to the efforts by the Clinton Administration to stifle the important and legitimate debate about inferences that can be drawn from the current State of scientific knowledge and about policies that are consistent with those inferences. On June 25, Vice-President Gore spoke at Vanderbilt University on the topic of "global warming" and stated:

> "There is a small group that likes to spread dissension and skepticism, just like the big tobacco companies spent huge amounts of money telling tobacco smokers smoking is not bad for you. . . . That's ridiculous and unethical." *The Tennesseean* (June 26, 1997).

On July 21, Interior Secretary Bruce Babbitt appeared on the Diane Rehm Show, and stated:

> "[I]t's an unhappy fact that the oil companies and the coal companies in the United States have joined in a conspiracy to hire pseudo scientists to deny the facts, and then begin raising political arguments that are essentially fraudulent, that we can't do this without damaging the economy . . . [T]he energy companies need to be called to account because what they're doing is un-American in the most basic sense."

This type of extreme statement makes it more difficult for the American people to gain a better understanding of the issue and for the Senate to gain the type of information necessary for it to discharge its constitutional responsibility. Very plainly, efforts to suppress the free exchange of information, evidence, and opinion undermine efforts to formulate a responsible national policy on climate change. The passage of Senate Resolution 98 by a vote of 95–0 will hopefully dissuade the Administration from continuing to pursue its "rush to judgment, cutoff debate" strategy. It is now clear that an open policy dialog—which necessarily includes an honest evaluation of the science of climate change—will occur and the Senate will independently distinguish the science from the pseudo-science.

Question 2. Since you support "appropriate action," I assume that you would prefer smart action to dumb action. By "smart action" I mean action that reduces emissions at lower cost than action that is costly.

Well, the acid rain trading program under the 1990 Clean Air Act has proven itself to be a smart kind of action, since it is reducing emissions fast and cheaply, spurring innovation, and dramatically lowering the costs of technologies.

I am told that a recent M.I.T. study has demonstrated this. It sounds to me like you are making an argument in favor of the "cap-and-trade" approach, with joint implementation or trading with developing countries as a key component. That would address, in a smart way, all of the concerns for "appropriate action" that you have raised. Your thoughts?

Answer. Your assumption that my use of the term "appropriate action" implies "smart action [as opposed] to dumb action" is correct. Let me clarify, however, that determining "appropriate action" is a two-step, sequential process:

(1) identify and substantiate the problem you are trying to solve and what result or target is necessary to solve it; and

(2) how to achieve that result or target most cost-effectively.

The Administration has emphasized being "smart" solely with respect to the second step above, without being "smart" on the essential first step.[1] Unfortunately, being "dumb" with respect to the essential first step renders the entire two-step process "dumb". Thus, joint implementation and emissions trading are options to be considered in the second step above. The GCC has long supported the concept of joint implementation, but questions the practicability and enforceability of an international "cap and trade" system for curtailing global greenhouse gas emissions. While "cap and trade" may seem like an attractive concept, a "cap" means rationing, which is a failed concept. However, the use of "smart", market-based tools to achieve a result that is not, in fact, yet warranted by the evidence, is not "smart". It is instead merely a "smart" way to address a dumb conclusion.

Your reference to the acid rain trading program of the Clean Air Act of 1990 is a useful one because it highlights the advantages of market mechanisms, the importance of serendipity, and the significant differences between the SO_2 trading program and an international tradable permits program for greenhouse gas emissions. First, the acid rain trading program did allow companies flexibility in meeting a performance goal, and that allowed cost savings compared to what would have occurred with a one-size-fits-all command and control program. Second, while the current market value of an SO_2 emission permit is below levels projected while the program was being devised, to a large extent this is the result of serendipity. For example, energy prices are lower than projected and deregulation in the transportation sector has allowed much greater use of low-sulfur coal. Third, there are immense differences between the United States SO_2 trading program and a program required for international tradable permits in greenhouse gases. The SO_2 program involved one gas, in one industry, in one country and the application of readily available technology. An international tradable permit program for greenhouse gases would involve multiple gases, multiple nations, plus every industry and every citizen in every country. Furthermore, short of suppressing energy use there is no practical technology for significantly reducing or sequestering CO_2 emissions. Obviously, an international tradable permits system would require a tremendous, unprecedented global monitoring and transactional infrastructure to ensure its integrity and enforceability. Whether political systems based upon national sovereignty could accommodate such an infrastructure is a serious question. Many, such as Dr. Richard Cooper (Harvard University) and Dr. Thomas Schelling (University of Maryland) have carefully considered these issues and concluded that "cap and trade" as well as joint implementation programs are simply not practical in any real sense. Cap and trade programs require allocation of the cap, and there is no generally accepted basis for such allocation. And to be cost-effective, both programs require major commitments by developing nations—commitments that are clearly not forthcoming. For these reasons, it is facile to suggest an easy parallel between the SO_2 trading permits program in the United States and a global emissions trading scheme for GHGs.

Question 3. You state in your testimony that, curbs on greenhouse gas emissions, "would be brutally expensive in terms of lost income, lost jobs and lost U.S. competitiveness on world markets." Curbs of any kind?

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[1] Testimony of Dr. Janet Yellen before the Committee on Environment and Public Works, July 17, 1997, p. 6: "[C]osts depend critically on how emission reduction policies are implemented. It boils down to this: if we do *it* dumb *it* could cost a lot, but if we do *it* smart *it* will cost much less . . ." (emphasis added). The GCC is still curious as to what the "it" is, as well as the justification for "it." [Step One Above].

Answer. The GCC's consistent promotion of "no" or "low" regrets measures to constrain the growth in greenhouse gas emissions obviously implies that there are opportunities to reduce emissions that would be benign economically and perhaps even beneficial. Many such opportunities have been embraced by industry to support voluntary efforts to achieve the "aim" of returning 2000 greenhouse gas emissions to 1990 levels. The U.S. Climate Action Report, released in May, reveals that over 5,000 private sector organizations participate in voluntary Federal climate mitigation programs, which are projected to reduce emissions by an estimated 75 million metric tons by the year 2000; consumer and business savings are projected at $10 billion by 2000 and $50 billion by 2010. Importantly, the Report documents that 94 percent of the U.S. primary aluminum production capacity has joined the Voluntary Aluminum Industrial Partnership; electric utilities representing 69 percent of 1990 electric generation and utility carbon emissions have signed the Climate Wise agreements; 2,300 companies now participate in the Green Lights program; and the Gas Research Institute has pledged $4 million of its annual budget to projects that reduce methane emissions. Widespread voluntary efforts such as these are an efficient, cost-effective way of speeding the adoption of economically viable energy efficient technologies. Such programs should help strengthen the already strong trend of increased U.S. energy efficiency.[2] In fact, the Energy Information Administration's 1997 reference case projection indicates annual decreases of 1 percent in energy consumption per dollar of GDP through 2015.

However, your quotation from my full Statement regarding "brutally expensive" curbs on greenhouse gas emissions appears as point 3 in the introductory summary. My detailed discussion of such costs relates to the Administration's intimation of agreeing to a legally binding U.S. commitment to stabilize emissions at 1990 levels in the next 12 years, by 2010.[3] In that regard *all* credible, independent economic analyses of the costs of dramatically curbing near term emissions—to 1990 levels by 2010—indicate the same result: *brutal expense* to our economy and people. Studies by Charles River Associates, DRI/McGraw Hill, the U.S. Energy Information Administration and economists at our most prestigious universities indicate that energy taxes of $125 to $200 per metric ton of carbon would be needed to suppress demand sufficiently to return emissions to 1990 levels by 2010 ($200 per ton is equivalent to an increase in the excise tax on gasoline of about 60 cents per gallon). A conservative estimate of the *annual* impact of a tax this size includes the following losses:

- $100 billion to $275 billion in GDP.
- 200,000 to 500,000 U.S. jobs.
- $65 billion to $100 billion in fixed business investment.
- $50 billion to $110 billion in consumer purchases.

On July 11, the Administration finally released a study by the Department of Energy (contracted through the Argonne National Laboratory). The study focused on "the potential effects on energy-intensive industries in the United States of alternative scenarios for changes in world patterns of industrial energy prices that might result from new climate commitments." The study results described the impacts on six industries (steel, cement, aluminum, paper, chemicals, and petroleum refining) as "significantly adverse" to "devastating," producing little, if any, environmental benefit.

In her testimony before the committee, Dr. Janet Yellen, Chair, Council of Economic Advisers, reported that the Administration's economic modeling efforts to predict the impacts of climate change policy were "futile." She stated that the Administration was left only with "a set of parameters and relationships that influence estimates of the impacts." It is, however, noteworthy that the May 30 Draft Report of the Interagency Analytical Team revealed that "[t]he starting point scenario [assuming stabilized emissions at 1990 levels by 2010] would raise the implicit price of carbon in the economy by about $100 per ton of carbon." The Report then described that "[a] permit price of $100 per ton is the equivalent of a price increase of 26 cents per gallon of refined petroleum product, $1.49 per thousand cubic feet of natural

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[2] Between 1973 and 1986, energy consumption per dollar of GDP declined 2.6 percent per year. Between 1986 and 1996, energy consumption per dollar of GDP declined 0.4 percent per year.

[3] Dr. Everett M. Ehrlich, who recently resigned his position as Undersecretary of Commerce for Economic Affairs, wrote in the *Washington Post* on June 15:

> ". . . the economic literature suggests that we could roll back our CO_2 emissions to their 1990 levels by 2010 for the equivalent of a 25 cent gas tax. It's not free, but it's not the end of the world."

In addition, on July 15 the Administration released its May 30 draft interagency study on the economic impacts of stabilizing CO_2 emissions by 2010 at 1990 levels.

gas, $52.52 per ton of coal, and 2 cents per kilowatt hour of electricity produced." *Draft Report*, Page 8.

This important effort, before it was abandoned by the Administration, was tending to confirm the severely negative economic costs of a policy to drastically curtail emissions in the near term. In fact, Dr. Yellen emphasized in her testimony that "[t]he speed at which emissions reductions are required can have large effects on the estimated costs. It is important to allow sufficient lead-time for orderly investment in new equipment and technology." This conclusion supports arguments made by the GCC in its July 1995 paper by David Montgomery, Charles River Associates, "Toward an Economically Rational Response to the Berlin Mandate." Others, such as Wigley, Richels and Edmonds in their January 18, 1996 article in *Nature* come to similar conclusions, namely that "[u]nanticipated changes will be costly. Time is therefore needed to reoptimize the capital stock." The GCC agrees and re-emphasizes that a 12-year period to return emissions to 1990 levels—requiring an approximate 25 percent reduction in projected fossil fuel use—would be brutally expensive. Even using Dr. Yellen's "remaining tools," we are unaware of any "parameters" or "relationships"—or existing technology for that matter—which avoids that result.

Question 4. Do you base your impacts assertions on the recent economic modeling done by the Charles River and Associates group? (If yes,) please talk some about the underlying assumptions in the Charles River Associate model, because a model as you know only *suggests* potential impacts. Does that particular model, for example, assume that the economy suffers *persistent* transitional inefficiencies (from actions to reduce emissions)?

Does it assume that there will be any energy source substitution? Does it assume inclusion of joint implementation or emissions trading, or any other flexibility instruments? Does it assume any benefits from averting climate change or other pollution damages? Is it reasonable to assume any of these at some level?

Answer. My statements regarding the economic impacts of policies to drastically limit greenhouse gas emissions and U.S. energy use are based on a broad spectrum of economic modeling efforts. In addition to work done by Charles River Associates, work by other groups such as MIT, the Energy Modeling Forum, DRI, and ABARE (Australian Bureau of Agricultural and Resource Economics) are also relevant and provide useful insights into the large impacts that should be expected from the targets and timetables proposed in the Berlin Mandate negotiations.

The question states that, "a model as you know only *suggests* potential impacts." This applies to models that project climate and the impacts of a change in climate, as well as to economic models that focus more on the impacts of climate policy. There is an apparent inconsistency in the Administration's confidence in modeling: why are economic models deemed "futile" in terms of projecting impacts in the next 20 years, while climate models predicting changes in the next 100 years are unquestioned? Thus, results of climate and climate impact models that are used to promote climate policies of the type being negotiated concern *suggested potential impacts* that *might* occur 100 or more years into the future. While some economic models cover a similar time horizon, most of the policy impact analysis done by the groups mentioned above focus on the next 20 or so years and evaluate the relatively near-term economic impact of proposed climate policies. It is very hard to deny that climate and impact models 100 years out are, by orders of magnitude, more unreliable than the economic models 10 or 20 years out. This is particularly true when you realize that the climate and impact models, for 100 years out, require inputs from economic models to even start their analysis. Assumptions regarding population, economic activity, technology, and lifestyles are all required before estimates of greenhouse gas emissions are generated for the next 100 years. Without that information, the climate models either have no emissions baseline to work with or are randomly picking scenarios that may have no relevance to the real world.

Regarding the CRA model, it assumes that market mechanisms would be used to create incentives for reducing energy use, thereby reducing carbon emissions, below baseline projected levels. These market mechanisms can be viewed either as carbon taxes or auctioned tradable permits, which are viewed by economists as being the least-cost way of reducing carbon emissions. Therefore, the model does not assume that the economy suffers persistent transitional inefficiencies specifically from actions to reduce emissions.

Transitional inefficiencies are more likely to be induced by the use of various command and control policies. In fact, since the model is of the type referred to as general equilibrium models, it arguably omits some transitional costs to the economy of moving to a lower-carbon trajectory, and therefore its impact estimates may be on the low side.

The CRA model does allow for substitution among different fossil fuels, as well as to non-carbon fuels. This substitution occurs depending on the relative prices of the fuels, including carbon taxes or tradable permit market values that raise the cost of carbon generating fuels. The CRA model, following the general structure of the Framework Convention on Climate Change as well as the Berlin Mandate language, assumes that each OECD country individually meets a proposed emission target.

The model is designed to help identify the economic costs of alternative emission reduction targets and timetables and does not attempt to address any possible benefits of lower carbon emission trajectories. While all policies should at least be evaluated with respect to likely costs and benefits, one difficulty with the climate change issue is that there are large near-term economic costs to reducing emissions substantially over the next two decades while it is unlikely that there would be any measurable benefits from reduced carbon emissions during that *same timeframe*, especially if developing countries are excluded from emission reduction requirements.

Returning to "transitional inefficiencies," there is a recent tendency to mischaracterize how economic models address the issue—are consumers efficient in their energy use and how efficient are they in changing their energy use. The recent World Resources Institute study, *The Costs of Climate Protection: A Guide for the Perplexed* is a prime example. For example, one of the six criteria the WRI study used to characterize model results was "inefficient economic responses." More specifically, it asked: "Is the model of the CGE type, which assumes that the economy adjusts efficiently in the long-run, or it is a macro model that assumes that the economy suffers persistent transitional inefficiencies?" This is a clear mischaracterization of the difference between model types, especially when the CGE results are labeled "optimistic" and the macromodel results are labeled "pessimistic." In reality the two types of models address different questions: the former asks what are the economic consequences of different equilibrium conditions (one with large carbon taxes and one without), and the latter asks what sort of costs arise during a policy-induced transition from one equilibrium to another. The difference between the models is sort of like moving from Washington, DC. to either Seattle or San Diego. The CGE model asks what life is like after you moved, while the macromodel focuses more on how you get to either location. It's like a vacation—getting there is at least half the fun, but if you cannot afford the travel portion, you do not take the trip.

Question 5. You talk about actions being considered by negotiators that would require us to "suppress energy use by at least 25 percent in little over a decade." What actions or proposals, now being seriously considered by international negotiators, would "require" this sort of response?

Answer. With less than 4 months before the Kyoto Conference of the Parties, United States negotiators still have not revealed to Congress or the American people the specific targets and timetables they intend to endorse. Apparently, the U.S. position will not be settled until late in the Fall. However, U.S. Government officials have consistently discussed and analyzed a commitment to return to 1990 emissions levels by 2010.[4] This past Spring, the European Union (EU) proposed a 15 percent reduction in 1990 emissions by 2010.

Comparing such goals with official U.S. Government projections of emissions clearly indicates that very large emissions reductions by the United States would be required. For example, Table A9 of the Energy Information Administration's *International Energy Outlook 1997* reports that U.S. carbon emissions for 1990 were 1.34 billion metric tons. The reference case projection for 2010 is 1.72 billion metric tons. Thus, to limit emissions to 1990 levels by 2010 would require a 22 percent reduction in emissions from the baseline. To limit emissions to 15 percent below the 1990 level by 2010 would require a 34 percent reduction in emissions from the baseline. As a practical matter, it is difficult to comprehend how emissions could be reduced by ⅓ off the baseline in little over a decade. Only very large carbon taxes, very high tradable permit prices, and/or an exceptionally long list of highly onerous command and control programs could suppress energy use sufficiently to achieve such emission reductions within that timeframe.

Question 6. If a treaty were signed that called for . . . let's say, a return to 1990 emissions levels by the year 2015: is the *only* way to get to that goal (that your group would support) a requirement that *all* countries, regardless of poverty level or current emissions contribution, take identical action at the same time? That is, should Togo, for example, be required to take the same actions as the United States and other OECD nations, and China, at the same time?

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[4] See footnote 3 regarding statements by Dr. Ehrlich and the May 30 Draft Interagency Study.

Answer. Any impact GHGs have on climate is independent of whether they come from developed or developing countries, and developing countries' emissions are projected to grow rapidly in the next century, outstripping those of the developed world by 2015, according to the Energy Information Administration. The purposes of the ongoing negotiations to amend the Framework Convention on Climate Change ("FCCC") are ostensibly to limit emissions, thereby limiting the potential of climate change. The Berlin Mandate of 1995, which exempts the developing world from assuming any treaty obligations, guarantees that total global GHG emissions will increase in the next century. As of now, therefore, the Berlin Mandate guarantees failure in addressing the objective of the FCCC. In addition, the flight of capital, jobs, and economic strength from participating developed countries to the exempted developing world would be an inevitable consequence of the Berlin Mandate.

In light of those realities, the relative burden of nations in addressing a global environmental risk is a daunting challenge that was recognized in the Berlin Mandate. Economic equity must be an essential part of any treaty negotiation, in spite of the difficulty in pursuing it. Many Senators supporting the unanimous passage of Senate Resolution 98 expressed the view that the Berlin Mandate, to which the Administration agreed in 1995, was a "fundamental error." President Clinton himself stated on August 4: "I believe the [Kyoto] agreement has to be a global one. I think all nations, developed and developing, should be a part of this." On this point, the GCC agrees with the President and the 95 U.S. Senators who supported Senate Resolution 98.

Question 7. You State that unnecessarily curbing carbon emissions will mean fewer jobs and less income. Does this prediction include all the new jobs that will be created by the shift to new technologies and industries?

Answer. Absent any identification of the "new technologies" that will enable, at the least, a 22 percent reduction in our use of fossil fuels within 12 years, it would be highly speculative to assume related "new industries" and "jobs." If technology does not emerge to accommodate an international commitment to reduce our use of fossil fuels by at least 22 percent, then painful policies to ration that use would be necessary. Prudent policymaking should prompt the question: What is the risk that a technology will not emerge which will enable a 22 percent reduction in our fossil fuel use in 12 years? Economist Robert Samuelson wrote in the July 9 *Washington Post*:

> "Without a breakthrough in alternative energy—nuclear, solar, something—no one knows how to lower emissions adequately without ultimately crushing the world economy."

JUL 2 9 1997

M. B. Oglesby, Jr.
President

ASSOCIATION
OF AMERICAN
RAILROADS

July 22, 1997

The Honorable John Chafee
Chairman
Committee on Environment and Public Works
United States Senate
Washington, DC 20510

Dear Mr. Chairman:

The Association of American Railroads (AAR)[1] submits these comments in connection with the Committee's July 10 and 17 hearings on the issue of global climate change. AAR asks that its comments be made a part of the hearing record.

AAR favors continued efforts by the scientific community to narrow the range of uncertainty about climate change. At present, however, the state of scientific knowledge does not justify the extreme measures being contemplated on the international level.

Background

In 1992, the United States and other nations ratified the Framework Convention on Climate Change whose objective is to reduce concentrations of greenhouse gases in the atmosphere to a level that will prevent dangerous interference with the Earth's climate.

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[1] AAR is a trade association whose members account for 77 percent of total line-haul mileage, produce 93 percent of total freight revenue, and employ 91 percent of the freight railway workforce.

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While scientists generally agree that the Earth's climate has warmed about 0.5 °C since the late 19th century, uncertainty remains about whether this is the result of human-induced climate change, or simply fluctuation within the range of normal climate variability.

As recently as last month, the respected journal Science reported, "Many climate experts caution that it is not at all clear yet that human activities have begun to warm the planet." Likewise, the Intergovernmental Panel on Climate Change, the world's leading body of climate experts, said in its latest report on climate change that slight variations in temperature "...cannot be considered compelling evidence of a clear cut cause-and-effect link between anthropogenic forcing [human activity] and changes in the Earth's surface temperature."

Despite these cautionary notes, the signatories to the Framework Convention on Climate Change in 1995 approved the so-called "Berlin Mandate" which calls for the adoption of a protocol or other legal instrument in Kyoto, Japan in December 1997 strengthening emissions reduction commitments for developed nations after the year 2000. The Berlin Mandate, however, specifically exempts developing countries from any new commitments -- despite the fact that their greenhouse gas emissions are rapidly increasing and are expected to surpass emissions of the U.S. and other OECD countries as early as 2015.

Economic Impacts

Near-term requirements to stabilize or reduce carbon emissions would be likely to produce significant economic dislocation in the United States, including profound job losses and major economic restructuring.

A DRI/McGraw-Hill study of carbon taxes as a means of reducing carbon emissions to 1990 levels by the year 2010 suggests that such an approach would lead to job losses averaging more than 500,000 per year. Economist Alan Manne of Stanford University, who studied abatement proposals intended to reduce carbon emissions to 80 percent of their 1990 level by the year 2010, found that such steps would result in annual losses ranging from 1.0-2.5 percent of the nation's gross domestic product.

Emissions reduction requirements would also have a sharply negative impact on international trade, with resulting higher fuel prices adversely affecting both industries

whose production processes are energy-intensive as well as industries which are dependent upon transportation between distant suppliers and manufacturing locations, and between manufacturing locations and ocean ports.

Nowhere in the world is the importance of transportation greater than it is in the U.S. In Western Europe, most manufacturing centers are located no more than a few hundred miles from ports. Distances to ports are even less in Japan, Taiwan, and Korea.

In the U.S., however, major manufacturing centers are often located far from ports. One critical industrial concentration is in the upper Midwest. An efficient transportation system is essential for these industries to play a vital role in the global marketplace.

Rail Impacts

Policies aimed at stabilizing or reducing greenhouse gas emissions levels would have a strongly negative effect on railroad customers and revenues. Based upon available sectoral analyses -- and depending upon the reduction targets and implementation alternatives selected -- AAR estimates that rail carloads would drop 8-16 percent by 2010, rail tonnage would drop 11-24 percent, and freight revenue would drop 7-15 percent.

In particular, emissions reduction requirements would have a pernicious effect on domestic coal production, which accounts for 59 percent of the fuel burned in electric utilities and comprises the largest source of revenue for the railroad industry. AAR estimates that such requirements would lead to a reduction in coal traffic and coal-related revenue of 25-54 percent. Chemical, auto, mining, pulp, and paper production would also suffer, causing further industrial and rail industry losses.

S. Res. 98

AAR supports S. Res. 98, a resolution calling upon the U.S. to refrain from signing any agreement regarding the Framework Convention on Climate Change which would cause serious harm to the economy or which would mandate new commitments to reduce greenhouse gases in developed nations unless the agreement also mandates "new specific scheduled commitments to limit or reduce greenhouse gas emissions for developing countries within the same period." The fact that the resolution has more than 60 Senate sponsors indicates that there is a high level of concern regarding precipitate governmental action.

AAR agrees with the Transportation Trades Division of the AFL-CIO, which earlier this year adopted a resolution calling on the Clinton administration to renegotiate the terms of the Berlin Mandate so that "all nations bear an equal level of responsibility for addressing concerns arising out of greenhouse emissions."

Until the world community reaches such agreement -- given the potential for crippling costs that would be inflicted with aggressive emissions abatement policies -- reasoned concern and study appear to be the most responsible ways to proceed. In that respect, AAR supports a coordinated international research effort, in addition to the continuation of the multi-billion dollar U.S. climate research program.

Sincerely,

M.B. Oglesby, Jr.

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