

**CLIMATE SCIENCE: EMPOWERING OUR
RESPONSE TO CLIMATE CHANGE**

HEARING

BEFORE THE

**COMMITTEE ON COMMERCE,
SCIENCE, AND TRANSPORTATION
UNITED STATES SENATE**

ONE HUNDRED ELEVENTH CONGRESS

FIRST SESSION

MARCH 12, 2009

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED ELEVENTH CONGRESS

FIRST SESSION

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THURSDAY, MARCH 12, 2009

U.S. SENATE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Committee met, pursuant to notice, at 10:10 a.m. in room SR-253, Russell Senate Office Building, Hon. John D. Rockefeller IV, Chairman of the Committee, presiding.

STATEMENT OF HON. JOHN D. ROCKEFELLER IV, U.S. SENATOR FROM WEST VIRGINIA

The CHAIRMAN. The hearing will come to order.

I thank our witnesses for joining us today. You've come from various places. From across the country, am I right? We're here to discuss climate change, which is a very big part of the work of the Commerce Committee, which a lot of people don't know, but they're going to.

There are some in this room who believe that climate change is for real and that I think it's for real. I come from a coal state. Not everybody likes to hear what I have to say about it, but I love my grandchildren. One of the questions I'm going to ask some of you is, When do you think the irreversibility factor becomes impossible to overcome?

There are also some that are a little less convinced of that. Not necessarily in this room, but certainly across the country and in some energy circles. For me, I believe the science is overwhelming. I think science determines everything—like Sir Isaac Newton said, "Follow the truth wherever it takes you," and you never move your nose from that direction. The danger of getting this wrong is very great, and therefore, we've got to act.

This Committee has a terrific jurisdiction on climate change, and I want people to be very clear about that, everything from ocean policy to science and technology policy, estuaries, transportation, and consumer affairs, just an enormous number of things. Each of the hearings we're going to have on climate change are sort of going to build upon the previous one. So, this is the base.

Today's hearing will be dominated by an area under the Committee's jurisdiction which people don't pay enough attention to, and that is something called, "science." The quality of our Nation's research in science is the single most important factor in meeting the challenges of climate change, it's the single most important factor in acting intelligently. If we're going to have a strong climate change policy, it requires strong climate science and our reaction

to that science. For science to be effective, it must be moved outside the laboratory so that the stakeholders can make use of it, so it's not just the knowledge itself, it's, How do you use the knowledge? Is it ready to be used?

The purpose of the hearing today is first, to provide an overview of the current state of climate change science, and second, to examine how science informs our response to climate change and what we do about its adaptation and mitigation strategies, and third, highlight challenges and knowledge gaps. What don't we know? What do we need to know? What do we know about parts of science, but not how to make it adaptable to the stakeholders, to the American people?

So, again, I think the time for arguing whether carbon emissions is a factor which affects the health of the Earth or whether our sea level is rising from global warming is, and must be, over. And until it is over, there will be a small drag on our momentum, but I think our momentum in the Congress is very strong on this.

We must address solutions now. We have to tackle the challenges very directly and intelligently. Those are two very different matters.

Today's hearing is about taking science out of the laboratory and into our communities in order to help people see how climate variability and climate change are impacting their lives every single day, whether they know it or not. From clean air and water to actually impacting our economy.

Climate affects every aspect of our economy. Over one-third of our Nation's gross domestic product is sensitive to weather and climate. Weather is a large part of what we do. And that fits very much into the science of prediction and all the rest of it. Where you build levees and where you do not, where will the sands increase, crops cease to grow? Science determines the types of crops that we grow, where we grow them; it affects where we live, where we build our roads, where we build our homes and our schools; and it determines the amount of energy that we need. And it affects our health.

Make no mistake, climate change is affecting our world in ways we are only beginning to understand. We have to let go of the "it isn't happening, because I can't see it." Well, actually you can see it. You just have to look up into the skies. But, we have to let go of that and understand that it's for real, before we can really move ahead effectively.

Climate change is affecting our world in ways that are dangerous. Warmer temperatures bring longer growing seasons, in some regions increasing agriculture production. We've seen severe storms that threaten coastal ecosystems. People think severe storms are acts of God or, you know, happenstance, or something that'll happen this 5 years, but not the next 5 years. Wrong. It's all a part of climate change.

Public health crises are very much involved in all of this, rapidly evolving through increased infectious and respiratory illnesses and weather-related mortality. The list goes on.

The economic consequences of climate change are equally grave. These issues are particularly important because of the serious challenges facing our economy. I know many Americans believe that

addressing climate change may have a negative impact on jobs, so let's consider that for a moment. However, the cost of inaction will be much, much worse than the economic impact of action. More importantly, action on climate change will produce new jobs and make our economy stronger.

In this crucial time in our Nation's history, dangerous time, the decisions we make now can and will set the course for many generations to come. We have the ability to improve our economy and the climate at the same time.

Through the decisions we make today, we can resolve to transition to a low-carbon economy, and increase sound climate science. That will drive effective decisionmaking, enhance stakeholder-driven climate science that directly addresses public needs and concerns and improve our ability to mitigate response and adapt to change. Anyway, the time to act is now.

Our Ranking Member, Kay Bailey—Senator Kay Bailey Hutchison, will arrive shortly, and when she does, I will ask her to speak, obviously. But, in the meantime, I look forward to hearing from our witnesses. They're going to talk about how we can improve climate science programs within the Federal Government to make them more stakeholder-driven and more responsive to the needs of society. I want to say a word about them.

Dr. Tim Killeen, with the National Science Foundation, will provide us with an update of the current state of climate change science, including research and data needs, gaps, what we don't know, and challenges to addressing those gaps and needs.

Dr. Kathy Jacobs, Executive Director of the Arizona Water Institute, works to connect science and decisionmaking—makes you a star—and engage stockholders to use climate change and climate variability information for water management, which is her work. She's also Chair of the National Academy of Sciences Panel on Adapting to Impacts of Climate Change.

Commissioner Sean Dilweg is the Wisconsin Commissioner of Insurance and former head of the National Association of Insurance Commissioners Climate Change Task Force. This is an industry beset with a lot to worry about. The insurance industry is one of the greatest financial sectors in the United States, and climate change will impact nearly every single segment of what they do, including health and life insurance, property damage, and on and on.

Dr. Jacobs and Commissioner Dilweg will help us understand the tangible link between science and its use. Reducing and stabilizing the concentration of carbon dioxide in the atmosphere will require a broad portfolio of solutions. A lot of people think that can't happen. Well, one of our witnesses, Mr. Alix, disagrees with that, and can prove it.

Mitigation strategies, such as carbon capture and storage, or sequestration, is important in decoupling climate-change-altering emissions from continued coal use. Now, this isn't a coal job, Frank. I don't want you to worry. But, you know, we're 70 percent now, and the question is, How do we get down to as low as we can? And you're going to have some very interesting things to tell us.

And there's the whole question of, How do you close the gap? If it's a big pie, and you've got renewables, right now at about 7 percent; you want to use atomic energy, that's another 20 percent, if

you want to do that; you've got weatherization, you've got all kinds of things. But, basically, you can't escape coal. It's the source for 51 percent of our electricity. And, in fact, in New Hampshire several years ago, it was literally 51 percent. West Virginia Coal was 51 percent of their electricity energy.

So, mitigation strategies such as carbon capture and storage are important in decoupling all of this with respect to coal use, creating a bridge to a low-carbon economy. Is that possible? Well, our fourth witness, Frank Alix, CEO of Powerspan Corp., will discuss how carbon capture and storage can help us bridge that in a very dramatic way.

So, I will now call upon our first witness, Dr. Killeen.
And here she is.

**STATEMENT OF HON. KAY BAILEY HUTCHISON,
U.S. SENATOR FROM TEXAS**

Senator HUTCHISON. Mr. Chairman, I do apologize. I had an unusually large constituent coffee this morning, and so, I am late, and I will not take any more of your time, because I know I'm late, but just to say that this is a very important issue to me. I think we need to do more in this area, and that's why I'm very appreciative that the Chairman has called this hearing so that we can move forward on really addressing the weather issues more clearly, and the scientific base for that. We need to know more. And I appreciate your calling this hearing, and I will certainly ask questions, but I don't want to take any more time right now.

Thank you.

[The prepared statement of Senator Hutchison follows:]

PREPARED STATEMENT OF HON. KAY BAILEY HUTCHISON, U.S. SENATOR FROM TEXAS

Thank you, Senator Rockefeller. I am pleased to join you in conducting this hearing on climate science. This Committee has a long history of advancing and promoting laws that are based on sound science.

Our Nation spends nearly \$5 billion per year on climate change activities. Given the current fiscal challenges to our country, it is important to ensure that these funds are allocated wisely. While conducting this research is important, it is equally important that this research is presented in a form that is useful to stakeholders and decisionmakers.

Accurate climate and weather science can have substantial benefits for both the private sector and local communities. It can help local communities plan future development and protect against natural disasters. As my home state of Texas continues to rebuild after Hurricane Ike, climate science can help us to make better decisions to prepare against future hurricanes.

Climate and weather science can also help us to develop new renewable energy technologies. Last Congress I introduced the Creating Renewable Energy through Science and Technology Act in order to promote renewable energy research and development in the areas of wind, wave, solar, geothermal, and biofuels production. Not only is a strong science program essential to developing these technologies the private sector needs a strong understanding of the environment to deploy these technologies efficiently. Understanding weather patterns is crucial when deploying wind and solar energy technology. Understanding ocean currents is necessary for making decisions of where to site wave and tidal energy technologies. We must use sound science to encourage innovation, and cost effective clean energy technologies that can help America reduce greenhouse gases and reduce our dependence on foreign oil.

We must also increase our efforts in weather modification research. In 2003, the National Research Council recommended the establishment of a coordinated Federal program of atmospheric research on cloud dynamics, cloud modeling, and cloud seeding, which would focus on fundamental research questions that currently impede progress and understanding of intentional and inadvertent weather modifica-

tion. In order to establish a coordinated Federal weather modification program I introduced legislation in both the 109th and 110th Congresses. This Congress I plan to introduce the Weather Mitigation Research and Development Policy Authorization Act of 2009, which I hope will lead to expanded weather modification research at both the Federal and local level. I urge my colleagues to support this legislation as it comes before this Committee.

The National Science Foundation currently spend about \$7 million per year on weather modification research but this pales in comparison to the economic costs of severe weather events. While we will not be able to stop Mother Nature entirely, we may be able alter her course, changing the weather in small, yet significant ways. Weather modification programs in Texas and other states are trying to use the latest technology to reduce the impacts of droughts by extracting more precipitation out of clouds. Many political subdivisions, like water conservation districts and county commissions, have embraced the technology of rain enhancement as one element of long-term, water management strategy. Research in weather modification will not only help us to mitigate severe weather events but will also help us to understand how weather impacts our Nation.

So as we look to research what the weather impacts of climate change will be in the future, we cannot sit idly by and wait. We must also conduct research into what and how we may be able to modify the weather of that time. I know as well as anyone that weather modification is a long-term investment, but given what's at stake, we have no other choice but to make the investment.

Our Nation needs to invest more in basic scientific research, math and education. Many of our greatest challenges, such as understanding climate change, weather patterns, and developing additional sources of domestic energy, will require significant additional funding and effort to answer some of the unresolved questions that have plagued policymakers.

I look forward to hearing the testimony of the witnesses. Thank you.

The CHAIRMAN. Thank you.

**STATEMENT OF HON. FRANK R. LAUTENBERG,
U.S. SENATOR FROM NEW JERSERY**

Senator LAUTENBERG. Mr. Chairman, I would make a request. And I so much appreciate the fact that you are holding this hearing concerning the critical question that faces us. And I wonder whether it's possible for those of us who have been here now—it's 10:20—to make a short statement, not more than 5 minutes, before the witnesses start. I'm very interested in what they have to say. These are an excellent group of witnesses. But, I think, in fairness, we might be able to get our statements out and come back to them, at the appropriate time, to be able to ask the questions.

The CHAIRMAN. Senator Lautenberg, at the beginning of our organizing, I made it very clear, as did the Ranking Member, that if we had a lot of people here, it would get very difficult and time-consuming to hear full statements, and people want to hear what the witnesses have to say. You can work your statement into your questions, but we agreed that the two of us would speak and then we would go directly to the witnesses, and then we would go directly to questions.

So, Dr. Killeen, I call on you.

**STATEMENT OF DR. TIM KILLEEN, ASSISTANT DIRECTOR,
GEOSCIENCES DIVISION, NATIONAL SCIENCE FOUNDATION**

Dr. KILLEEN. Thank you very much, Mr. Chairman. Is this working? Chairman Rockefeller and Ranking Member Hutchison and Members of the Committee, I'm honored to speak to you—with you today on the state of climate change science. And I want to particularly thank you for your opening remarks on the part of the sci-

entific community, and the leadership that you're demonstrating here and by the mechanism of this Committee.

My name is Tim Killeen. I'm the National Science Foundation's Assistant Director for the Geosciences. I'm also the former Director of the National Center for Atmospheric Research and the past President of the American Geophysical Union, which is the world's largest organization of geoscientists. My academic background includes teaching and research in atmospheric, space, and earth-system sciences.

Today's topic is of tremendous importance to the understanding of our planet and to our stewardship of it. And I'd like to make three simple, but fundamental, points in my testimony:

First, the science of climate change has advanced to where we now understand, quantitatively, the basic drivers of both the observed natural and manmade changes, which is a supreme accomplishment of modern science and the scientific method.

Number two, we are now poised to take that knowledge and expand it in order to develop the tools, precisely those that you were alluding to, Mr. Chairman, that policymakers require for future effective decisionmaking, predications of future change at the temporal and spatial scales of relevance to people's lives.

Third point is that the U.S. scientific and engineering community can and must retain world leadership, both intellectual and technological, and continue to push scientific frontiers that will allow us to predict climate and weather on scales relevant to human activities and endeavors.

So, I'd like to begin with some of the things that we do know, representing the fruits of research by the hundreds of climate scientists, many of whom are from the U.S., many of whom were involved in the recent Intergovernmental Panel on Climate Change, or the IPCC, the fourth assessment, as authors and reviewers. Their famous phrase from the most recent assessment summarizes it well, "Warming of the climate system is unequivocal, as is now evident from observations in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."

So, we know many things. We know that the Earth is warming—it's warmed, over our whole lives, everybody in this room; the strength and pace of this warming is unprecedented—this warming is linked to human activities, especially the release of carbon dioxide and other greenhouse gases, but also deforestation; that significant continued warming is unavoidable, and we will be adapting to that; and that changing climates have already significantly impacted people, infrastructure, and ecosystems across the globe; and that these impacts will increase in extent and severity.

The surplus heat energy in the oceans means that atmospheric warming will continue into the future. The rate of warming and the possibility for stabilization of the climate system will depend on human choices over the next years and decades.

The investigation of global warming is a story of scientific accomplishment. We're proud of that. It was forecast well, back in the previous century. Current models capture the evolution and global patterns of recent climate change remarkably well over the last century. And projections for the long-term centennial climate are

credible. Our observing systems, though incomplete, monitor changes in the global environment with unprecedented accuracy and precision.

These research efforts are interdisciplinary, intergovernmental, and international. Scientific understanding of global climate change is growing rapidly. The knowledge from the fourth assessment from the IPCC is invaluable, but it's based on research that was conducted more than 5 years ago. The IPCC's estimates of the pace and severity of global change were probably conservative. Global emissions of greenhouse gases and their consequences are increasing faster than had been predicted or projected at that time. And we recognize now that natural systems have thresholds that could result in rapid changes, that identifying and understanding those thresholds remains a scientific challenge.

Today, we know that the Earth functions as a system, affecting ice, carbon, rainfall, nitrogen cycles, ecosystem responses, and the likelihood of extreme weather events. But, we still lack the full detailed predictive understanding of that system and its many rich interactions. The science of climate change is not over, it's just getting to a new threshold.

In my written testimony, I've provided various examples of specific current research challenges, because you asked for gaps in our knowledge, and I won't reiterate them in my oral remarks, but we recognize that being able to provide decisionmakers with useful predictions means that public policy, economic development, and human behavior must be taken into account, as well as the biological and physical sciences. We have entered a new, exciting, but very challenging, scientific world, where traditional national science—natural science, social science, and policy sciences must intersect.

Society must find a way to deal with the impacts of continued warming, but a rational basis for mitigation and adaptation choices in assessing their potential consequences must be established and must be informed by the very best science and engineering we can muster. And this knowledge must continue to be improved over time. And, Mr. Chairman, you made that very point in your opening remarks.

We've reached a point where the required detailed predictions are within reach because of the scientific advances over the past few years, but scientists must also find new ways to convey to non-specialists the uncertainties of their predictions and to develop tools that allow decisionmakers to incorporate relevant information into the decision process.

The predictive knowledge base to inform sound and effective policy—and this is my personal opinion—is perhaps the most important gift science will ever yield to humanity.

The U.S. leads the world in research in the natural and social sciences and engineering disciplines today. The significance of the climate problem demands that the U.S. take a lead in its solution. And the U.S. scientific community is poised to take up that challenge.

Mr. Chairman, I appreciate the opportunity to appear before the Committee and speak with you on this important topic. And I

would be pleased to answer any questions that you may have, to the best of my ability.

[The prepared statement of Dr. Killeen follows:]

PREPARED STATEMENT OF DR. TIM KILLEEN, ASSISTANT DIRECTOR,
GEOSCIENCES DIVISION, NATIONAL SCIENCE FOUNDATION

Chairman Rockefeller, Ranking Member Hutchison, and Members of the Committee, I am honored to speak with you today on the state of climate change science.

My name is Tim Killeen, and I am the National Science Foundation's Assistant Director for Geosciences. I am also the former Director of the National Center for Atmospheric Research, and the Past President of the American Geophysical Union (AGU). My academic background includes a professorship at the University of Michigan, where I taught and conducted research programs in atmospheric, space, and Earth system sciences for many years.

The topic of this hearing is of tremendous importance to our understanding of the planet on which we live and to the stewardship of our world. I wish to make three simple but fundamental points: (1) the science of Earth's climate and climate change has advanced to the point where we now understand the basic drivers of the natural and man-made changes in the Earth's climate system—this is a supreme accomplishment of modern science and the scientific method; (2) we stand poised to expand that understanding and to begin to develop the detailed knowledge policy-makers require for effective decisions that will surely shape our world for generations to come; and (3) the U.S. scientific and engineering, community can and must retain world leadership through our intellectual and technological capabilities to continuously improve predictions of climate changes on the temporal and spatial scales relevant to human endeavors.

What We Know

The many hundreds of climate scientists involved in the Intergovernmental Panel on Climate Change (IPCC) summarized the situation in their famous phrase: "Global warming is unequivocal" (IPCC AR4). We know that:

- the Earth is warming (more than 1 degree Celsius since 1860).
- the strength and pace of this warming is unprecedented in at least the past 1,000 years.
- this warming is linked to human activities, especially the release of carbon dioxide and other "greenhouse gases."
- significant continued warming is unavoidable.
- changing climates have already significantly impacted people, infrastructure, and ecosystems throughout the globe, and these impacts will increase in extent and severity as climate changes continue.

While global warming represents a profound challenge to Earth's people, its investigation is a story of scientific accomplishment. Global warming was forecast by simple theories and models well back into the previous century. Our current models capture the evolution and global patterns of climate change over the past century remarkably well, and they make credible and reproducible projections for the long-term climate outcomes of greenhouse warming. At the same time our observing systems, although incomplete, monitor changes in the global environment with unprecedented accuracy and precision.

Our knowledge is expanding. Driven by intense research efforts that are interdisciplinary, inter-governmental, and international, scientific understanding of global climate change is growing rapidly. Recent advances build on the understanding contained in the IPCC 4th Assessment (AR4, 2007), which is based on research conducted more than 5 years ago. We now know more about how the Earth functions as a system—the role of ice, carbon, rainfall and nitrogen cycles; ecosystem responses; the likelihood of extreme event occurrence (*e.g.*, wildfires and heat waves) and more. A body of recent research compiled in the U.S. Climate Change Science Program's Synthesis and Assessment Products (SAP) has been very helpful in expanding our regional knowledge in these areas.

Because of the accumulation of surplus heat energy in the ocean, atmospheric warming will continue long into the future, but the rate of this warming and any possibility for ultimate stabilization of this system will be dependent on how humans adjust concentrations of atmospheric greenhouse gases over the next years and decades.

What We Need to Know

As the pace of global change has accelerated, so has the demand from the public, business leaders, resource managers, and decisionmakers for climate predictions, not just a century ahead but over the next five, ten, or fifteen years, and not just globally, but regionally and locally. Led by U.S. researchers, the scientific enterprise can meet this demand, but must first fill fundamental gaps in our understanding of the Earth system and build new technologies for Earth-system prediction. Traditional research in fields like meteorology, oceanography, geology, glaciology, biology, and the social sciences must be linked to construct an understanding of the Earth-system including the impact of, and on, its human inhabitants. Underpinning all of this is the need for a comprehensive, high accuracy, high-spatial and high temporal resolution, stable, continuous, sustained global climate observing system that includes physical, biological, and social observations not only to monitor climate change but for use in research and modeling.

Results of interdisciplinary research efforts must then be used in developing computational models with verifiable predictive skill. These next-generation predictive models will need to be run on our most powerful computers that can store, display, and analyze, and similarly handle the ever-growing volumes of observational data used to further refine the models. New computational methods are needed to make the best possible use of our computing power. Finally, new knowledge and techniques in mathematics, statistics, information sciences and cyber-infrastructure are crucial in converting model results to quantifiable statements about the various impacts and risks posed by climate change.

What Are Some of the Leading Scientific Challenges?

Regional Climate Change

While our understanding of average global climate change and the large-scale factors driving it are fairly well understood, we have yet to develop the capability to predict accurately how climate will change on a regional basis. Some parts of the globe, such as the Antarctic Peninsula, are warming much faster than others and the factors driving these local variations are not well understood. A key challenge to the research community is to identify and understand these smaller scale factors and to incorporate them into models that will predict reliably how communities and specific parts of the globe will be impacted by climate change.

Ice Sheet Changes and Rising Sea Levels

Rising sea levels are a major consequence of global warming. As the oceans warm, their waters expand. This effect is comparatively well understood and predictable. What is less understood and less predictable is the behavior of ice sheets and the possibility of great and rapid rises in sea level due to melting ice caps. The ice sheets of Greenland and Antarctica hold vast volumes of water. Because of uncertainties surrounding the behavior of ice sheets, their impact on sea level rise was not adequately addressed in the last IPCC assessment. Recent observations including increasing areas of summer melt on the surface of the Greenland icecap and space-based observations of decreasing ice-sheet mass suggest the potential for a 0.6–1.9 feet rise in sea level this century (SAP 3.4). Low lying regions, vital coastal wetlands and, in the developing world, densely populated agricultural regions could be inundated as a result of rapid sea level rise.

In the U.S. alone, protecting coastal infrastructure against such a rise could require continuing investments of billions of dollars. At present, however, we cannot make reliable statements on the likelihood of a disastrous rise in sea level because of our limited knowledge of how ice sheets work. Recent research suggests that some previously unknown or neglected processes, such as the lubrication of ice flow by surface meltwater which reaches the base of the ice sheet through crevasses, are important, but we are not yet at the point of incorporating these effects into predictive models (SAP 3.4). Other recent results suggest the importance of increasing ocean temperatures on the retreat of Greenland outlet glaciers and the diminishment of the ice sheet. Finally, the impact of sea level rise on coastal ecosystem may be significant and likely will have far reaching consequences to inland-oceanic processes, including freshwater quality and availability.

Water Scarcity

Three decades ago, climate modeling pioneer, Sukyuro Manabe, predicted that global warming would lead to reductions in rainfall in some of the Earth's most productive agricultural regions. The increased frequency of drought in places such as the southwest U.S. suggests that this trend may be underway (SAP 3.4). While models generally agree that the planet's subtropical dry zones are expanding, there is great disagreement among them in regard to the pace and severity. Within the trop-

ics, the uncertainty is greater. For example, there is nearly perfect *disagreement* among models as to whether the Sahel region of Africa will become wetter or drier in this century. In the monsoon regions of South Asia a layer of haze, air pollution from industry and household fires, causes more sunlight to be absorbed within the atmosphere and less at Earth's surface. Some models predict that this change could result in a weakening of the Asian monsoon and more frequent failures of monsoon rains, but once again, the pace and strength of this effect is highly uncertain.

While our current models can address the global scale, they have not yet been fully adapted to regional and local scales. The water used by people, however, comes from local sources (*e.g.*, wells, lakes and rivers recharged by rain and snow). At this stage, our models provide little information on these scales, which are small when viewed globally but critically important to a farmer or a water manager. Models that can provide information on the scales that users need are coming, but they are still in their infancy.

Ocean Acidification

Roughly one third of the carbon dioxide humankind has released from burning fossil fuels has gone into Earth's oceans (IPCC AR4). While ocean uptake has slowed the pace of global warming, it has been harmful to living things in the ocean. When carbon dioxide dissolves in the ocean, it makes seawater more acidic. Observations verify that the ocean has become more acidic, and, as this trend continues, it will make the ocean environment less and less hospitable for many key organisms, especially those that build hard shells, such as corals. While the basic chemistry of this problem is well understood, there are many questions we cannot yet answer: How will ocean ecosystems respond to increased acidity? How does ocean circulation, and its potential changes in a changing climate, affect how much carbon dioxide is absorbed and how rapidly the ocean acidifies? What are the implications of ocean acidification on marine ecology and the sustainability of fisheries and how might it affect the capacity of the ocean to continue to absorb carbon-dioxide? Ocean acidification is but one example of how questions about climate change extend beyond traditional climate science into other parts of the Earth system. In this case, a complete and coupled understanding of marine ecology along with climate physics is needed.

Methane Gas

Even when we look to the past, we are confronted by questions about the interrelationships between greenhouse gases and other environmental phenomena. For example, from ice cores drilled in Greenland and Antarctica, we know that in Earth's recent geologic past (hundreds of thousands of years) the concentrations of two greenhouse gases, carbon dioxide and methane, have varied nearly in lockstep with Earth's temperature (IPCC AR4). The changes in greenhouse gases must have played a significant role in the temperature changes, while, at the same time, and by mechanisms we still do not fully understand, changes in temperature caused changes in levels of greenhouse gases. We do not know if the processes that caused carbon dioxide and methane to change naturally in the past could still function today in a warmer climate. If they do, the implications for global warming are profound, as they would function as a positive feedback loop, increasing the rate of global warming. Great quantities of methane are sequestered in Arctic permafrost. This methane may be released to the atmosphere as Earth warms and the permafrost melts, but we do not know how much or how fast (SAP 3.4).

Extreme Events

Researchers have already observed that an increasing portion of the rainfall comes in intense events. Two general implications of this trend are that the risk of flooding is increasing and that the fraction of rainfall that runs off may be greater. Recent modeling results suggest that as the Earth warms severe local storms and the damages from flash floods and high winds will increase (SAP 3.3). Further, the time between rainstorms may increase (SAP 3.3), which could lead to greater fire risk and water-stress to crops. Currently, our ability to make quantitative and precise statements about these risks that would be useful to emergency planners, farmers, and flood-control engineers is limited. Once again, the limitation comes from the scales of our models. The present generation of global climate models is far from being able to represent a locally severe thunderstorm or the time between storms.

Biodiversity and Ecosystem Function

The Earth's climate and related life support systems are changing today at highly accelerated rates that are markedly different from those experienced by living systems in the recent geological history. The processes associated with climate change,

as well as the mechanisms available to mitigate it, are largely biological—every part of the Earth is affected by the seemingly endless ability of living organisms to transform the world around them. The relationship between the Earth’s ability to function as a set of interconnected ecosystems and the biodiversity within and among those interacting systems is an area of incomplete knowledge and critical importance. Research that builds a mechanistic understanding of carbon, nutrient and water cycles and the connections with living systems; that connects carbon and nutrient cycles to land use changes; and that identifies likely continental sinks of CO₂ is necessary to fill gaps in the climate change picture and directly relevant to human well being. Finally, achieving an understanding of the linkages between the biological and physical Earth systems and social systems is needed. Maintaining a healthy planetary ecosystem depends on both the maintenance of the Earth’s biodiversity and its ability to respond to changing conditions.

Human Health

In the summer of 1995 a heat wave in Chicago caused 521 deaths; the European heat wave of 2003 killed 35,000 people. Careful statistical and modeling studies indicate that the European heat wave was probably related to global warming (IPCC AR4). As the global temperature rises, the risk of severe heat waves is expected to increase. Yet we are limited in our ability to predict future heat waves and their impacts on people. Our models are not yet able to represent the complex urban environment where heat waves are most severe. Further, the impacts of heat waves depend on the vulnerability of urban populations and how they and community leaders respond when the thermometer spikes.

Heat waves are but one example of how global climate change can influence human health. Others include the spread of disease agents and vectors into new areas, such as from tropical to temperate regions and to higher latitudes and altitudes. Other examples include key findings from SAP 4.6 which include: (1) Hurricanes, extreme precipitation resulting in floods, and wildfires also have the potential to affect public health through direct and indirect health risks; (2) The impacts of higher temperatures in urban areas and likely associated increases in tropospheric ozone concentrations can contribute to or exacerbate cardiovascular and pulmonary illness if current regulatory standards are not attained; and (3) There will likely be an increase in the spread of several food and water-borne pathogens among susceptible populations depending on the pathogens’ survival, persistence, habitat range and transmission under changing climate and environmental conditions.

In all of these cases, a useful estimate of the risk depends on more than predicting changes in the physical climate, even if we can do so at the small scales of a city neighborhood. Biology, ecology, and human physiology come into play, and, even more importantly, human responses. We must better understand the human and social dimensions of climate change if we are to address the wide range of climate change problems, but the scientific study of these human factors is in early stages.

Smart Adaptation and Smart Mitigation

It is imperative that society adapts to the impacts of continued warming of the climate. The extent to which we will need to adapt will depend substantially on future emissions and the success of mitigative efforts. Anticipating the magnitude of potential impacts is complicated by other factors such as population growth, urbanization, the availability and implementation of new technologies, the health and resilience of natural systems and human communities, and pollution, which can amplify or exacerbate the impacts due to changing climate. Current climate projections are based largely on scenarios that assume no particular climate policies with respect to greenhouse gases (IPCC AR4), however, policy choices will, in fact, affect how natural and human systems respond, perhaps in unexpected ways.

Society will need to pursue a mix of smart adaptation and mitigation strategies. Identifying the best sets of options requires tools that allow us to understand how the Earth’s physical, biological and human systems will respond to various adaptation and mitigation strategies and the tradeoffs with respect to effectiveness and cost. Factors of politics, economic development, and human behavior and health must be taken into account. These requirements bring us into a new and very challenging realm where traditional natural science, social science, and policy sciences all intersect.

Potentially Disruptive Climate Change

Studies of ancient climate change have shown evidence of dramatic changes in the Earth’s climate. Much new work focuses on possible “tipping points” or thresholds, at which a system undergoes rapid and dramatic change. Such events occur rarely, but carry high consequences when they do. For example, during the 1990s, Alaska

experienced the largest outbreak of spruce bark beetles in the world. This outbreak was associated with a threshold response to milder winters and warmer temperatures that allowed more beetles to survive the winter (SAP 4.2) The concept also applies to social and economic systems. Identifying potential tipping points in our natural and social systems is challenging because many systems are nonlinear, but fully informed decisionmaking by policymakers will need to take the possibility of tipping points into account.

Dealing with Uncertainty

No matter how sophisticated our models and predictive capabilities there will always be uncertainties in the projections and the risks of adopting particular strategies cannot be fully known. Scientists must find new ways to convey to non-specialists the uncertainties of their predictions and develop tools that allow decision-makers to incorporate the information into the decision process.

The Ultimate Goal

The goal of climate change science is to make verifiable quantitative predictions. We need this predictive capability for two reasons. First, and most importantly, societies need them to respond intelligently to the challenges posed by a changing climate. At the same time, as scientists, we know our understanding can be tested only by making predictions and comparing them with what actually happens—this is as true today for global climate change as it was for predicting the orbits of the planets in the days of Kepler and Newton. Getting to a useful predictive capacity requires scientific understanding of the myriad processes and interactions that comprise the Earth system. It requires constructing computational models that incorporate our understanding. It requires access to our best supercomputer hardware and the development of computational methods to implement these models. It requires observations of all aspects of the Earth system, including its human dimensions, that can be used as the starting points for model predictions and as data for testing the accuracy of models. And it requires the human and cyber infrastructure to deliver model results to people in forms and media that they can use.

As noted previously the scientific community has made remarkable progress in gaining an understanding of climate relevant processes and the ability to model these processes to give a realistic representation of the current climate system on a global scale and how human activities have begun to impact climate. There really is no longer a question of humankind's perturbation of the climate. The question now is the timing and the magnitude of climate change that will occur in the future.

Conclusion

Society cannot avoid the need to adapt to the impacts of continued warming of the climate due to past emissions of greenhouse gases, but policy and decision-makers need a rational basis for deciding how to proceed and an understanding of the potential consequences of their choices. Climate Science has progressed to the point where the detailed predictions required are within reach, once a set of definable scientific challenges is overcome. The predictive knowledge base to inform sound and effective policy is perhaps the most important gift science will ever yield to humanity.

The U.S. leads the world in research in the natural and social sciences and engineering disciplines and in developing computing hardware and computational tools. The significance of the climate problem demands that the U.S. take the lead in its solution. The U.S. science community is poised to take on this challenge.

Mr. Chairman, I appreciate the opportunity to appear before the Committee to speak to you on this important topic. I would be pleased to answer any questions that you may have.

The CHAIRMAN. Thank you.

Ms. Jacobs.

**STATEMENT OF KATHARINE JACOBS, EXECUTIVE DIRECTOR,
ARIZONA WATER INSTITUTE**

Ms. JACOBS. Chairman Rockefeller, Ranking Member Hutchison, Members of the Committee, thank you so much for the opportunity to speak with you today as you consider how best to prepare this country for the impacts of climate change.

The current and potential impacts are undeniably of concern. Drought and unreliable water supplies, more intense storm events,

sea-level rise, and large wildfires are already attributed to global warming, and are predicted to increase over time. While the focus to date has primarily been on reducing carbon emissions, adaptation issues need more attention.

My name is Katharine Jacobs, and I am the Executive Director of the Arizona Water Institute, which is a consortium of Arizona's three State universities focused on water sustainability.

For 23 years, I was a Water Manager for the Arizona Department of Water Resources, and I'm currently a Professor at the University of Arizona. I've worked on drought planning, water conservation, groundwater management, climate change and Colorado River issues, and I currently chair a National Academy Panel on Adapting to the Impacts of Climate Change.

Though we've made great strides in understanding climate variability and climate change from a scientific perspective, much of that information is lost on the American public and on water managers who need it. I have been in countless meetings where this gap between science and society has been lamented, but, with a few notable exceptions, very little progress has been made in addressing this problem.

Our current ability to connect science and decisionmaking is woefully inadequate, and a big part of this problem is communication. At a very basic level, the science and management communities often fail to understand each other's vocabulary and their motivation.

An associated problem is that, to a layperson, the messages that come from scientists and science agencies often appear to be in conflict. Climate change information has been highly politicized, leading people to incorrect conclusions about the quality of the information and the degree of certainty that does exist. This means that the context for building the proposed National Climate Service is especially challenging.

Possibly the biggest challenge is funding. A minute portion of the Federal science budget is spent on translating that science into useful decision-support tools and timely, relevant sources of information. There is a lot of focus, especially within NOAA and NASA, on buoys, satellites, and massive computing capacity. All of these investments have dramatically improved the understanding of science; however, to truly translate data into information, and information into knowledge, requires a larger investment in decision-support tools, data access, training, and capacity-building.

The only way that the new National Climate Service will succeed is if it empowers a multitude of regional support networks and centers to engage the public and decisionmakers at local scales, where decisions affected by climate are made on a regular basis.

Fortunately, we do have examples of successful bridging organizations, such as the NOAA Regional Integrated Science Assessment Program, with which I have been associated for some years. But, this network will have to be informed by a well-coordinated Federal science team, and the network itself will need to be well supported by Federal money.

Based on recent national and international reports, the water supplies of the West are seriously threatened by climate change. This is, in part, because higher temperatures alone have dramatic

impacts on the hydrologic cycle, drying soils, reducing runoff into rivers, causing more evaporation from reservoirs, and increasing the demand for water for people and for ecosystems.

Recent climate-model information suggests that the Southwest will likely also experience reduced precipitation. The result could be relatively dire for the Colorado River, including a potential 20-percent decrease in flows by the year 2050. This is not a happy circumstance for the nearly 30 million people who depend on its flows.

But, most water managers do not even know about the Climate Change Science Program. It is clear that coherent messages regarding climate science are not penetrating into arenas where they can best be used. Significant restructuring of the program will be required so that regional issues, like water-supply reliability in the Colorado River Basin, can be effectively addressed.

In the written version of my testimony, I have outlined what I believe are the key ingredients of a successful Climate Service that will connect science and decisionmaking. In the interest of time, I will just say that the Climate Service needs to have a broad, inclusive vision; that the engagement, training, capacity-building, and coordination functions need to be expanded and adequately funded; that it should address both climate variability and climate change at multiple time and space scales; and that it will require strong leaders who have the authority to either encourage or force the integration of Federal science capacity to support decisions.

By some accounts, the U.S. Government has spent more than \$30 billion in the last 8 years on climate science, and perhaps \$100 billion total. Given the magnitude of this investment, it is clearly time to take stock of what we do know, and, though we haven't answered every question, empower decisionmakers to access and use that information with full understanding of its limitations.

Clearly, we need to keep investing in research on both climate variability and on climate change, but it is time to get more value out of the investments we've already made.

Thank you very much for the opportunity to comment on this extremely important topic. If you have any questions, I would be happy to respond.

[The prepared statement of Ms. Jacobs follows:]

PREPARED STATEMENT OF KATHARINE JACOBS, EXECUTIVE DIRECTOR,
ARIZONA WATER INSTITUTE

Chairman Rockefeller, Ranking Member Hutchison, Members of the Committee, thank you for the opportunity to speak with you today as you consider how best to prepare this country for the impacts of climate change. Many in this country still do not consider this topic a "front-burner" issue. But the current and potential impacts of climate change are undeniably of concern: drought and unreliable water supplies, more intense storm events, sea level rise, large wildfires and devastating bark-beetle damage to forests across the west already are attributed to global warming and are predicted to increase over time.

My name is Katharine Jacobs, and I am the Executive Director of the Arizona Water Institute, a consortium of Arizona's three state universities focused on water sustainability. Since 2003, I have been a Professor in the Department of Soil, Water and Environmental Science at the University of Arizona in Tucson. For the prior 23 years I was a Water Manager for the State of Arizona, and for 14 of those years I was Director of the Tucson regional office. I also briefly managed Arizona's drought planning program, and have worked extensively on water conservation, groundwater management, climate change, western water policy, and the Colorado River. In collaboration with a wide range of Federal and university experts, I wrote

the water sector chapter for the first National Assessment of the impacts of climate change, published in 2000. I currently chair a National Academy panel on Adapting to the Impacts of Climate Change.

My comments are directed toward adaptation to climate impacts, rather than on limiting carbon emissions. Although these activities need to be considered in tandem to avoid unanticipated consequences and to optimize investment, conversations about mitigation have been ongoing for some time. Discussions of adaptation are long overdue.

Translating scientific information into useful knowledge for decision-makers is my particular interest. I am focused on climate science, because better use of this information would be of enormous benefit to society in general, and water managers in particular. Two important observations: (1) although we have made great strides in understanding climate variability and climate change from a scientific perspective, much of that information is lost on the American public and on the water managers who urgently need it to reduce risk and increase economic opportunities, and (2) most scientists have a limited understanding of the information needs of decision-makers. I have been in countless meetings where this gap between science and society has been lamented, but with a few notable exceptions, very little progress has been made in addressing this problem.

I would like to emphasize three key points in my testimony:

1. Our current ability to bridge the gap between science and decision-making is woefully inadequate, and despite billions of dollars spent on the Federal climate program, it has not been as effective as it would have been if it were more focused on building adaptive capacity.
2. Adaptation decisions are made at the state, regional and local levels—and the magnitude of the climate change challenge is so great that new mechanisms of engagement are required to build local and regional capacity to respond.
3. The climate service needs to have a broad, inclusive vision; be adequately funded; address both climate variability and climate change at multiple time and space scales; and have the authority to either encourage or force the integration of Federal science capacity to support decisions

Connecting Science and Decision-Making

In 2001–2002 I had the good fortune to take a sabbatical from the Arizona Department of Water Resources to work for what at the time was NOAA's Office of Global Programs (now the Climate Office). While there, I worked on the issue of why Federal climate science often does not get used by water managers or decision-makers more generally. I spent some of that year interviewing both climate scientists and people who studied the use of scientific information, and concluded that although all of the scientists and the agencies for which they worked had good intentions, a variety of factors accounted for the failure to connect science and decision-making. I wrote a workbook based on my findings called *Connecting Science, Policy and Decision-Making: A Handbook for Researchers and Science Agencies*. I have provided copies to your staff.

A big part of the bridging problem is communication: failure of scientists to understand how the information they generate can best be used, and failure to understand the political, institutional and economic context of decisions. Meanwhile, resource managers lack trust in “academic, ivory-tower” information or mistrust the government in general; and they often are reluctant to innovate and use data and tools from new sources. At a very basic level the science and management communities often fail to understand each other's vocabulary and motivations.

A second concern is that scientists aren't always that good at talking with each other. They come from different disciplinary backgrounds (hydrologists, atmospheric scientists, oceanographers, etc.), and often “stick with their own kind.” Because climate issues are by nature interdisciplinary, this can be a serious problem.

A third big problem is that to a layperson, the messages that come from scientists and science agencies often appear to be in conflict. In the case of climate change, information has been highly politicized, leading people to incorrect conclusions about the quality of the information and the degree of certainty that does exist. For reasons that are unclear, people are willing to tolerate high degrees of uncertainty in most other aspects of their lives, but the bar is set exceedingly high for climate information. This means that the context for building the proposed national climate service is especially challenging.

A fourth challenge, possibly the biggest, is funding: a minute portion of the Federal science budget is spent on translating that science into useful decision support tools and timely, relevant sources of information. There is a lot of focus, especially within NOAA and NASA, on buoys, satellites and massive computing capacity. All

of these investments have dramatically improved the understanding of underlying processes, atmospheric physics, land surface-atmospheric interactions, etc. However, translating data to information, and information to knowledge, requires a larger investment in decision support tools, data access, training and capacity building.

Like many other scientific topics, climate science is complicated. Climate change presents so many scientific and social challenges, across regions and economic sectors, at multiple scales of time and space, that building more capacity to translate climate information for specific applications is a daunting task. The only way that the new national climate service will succeed is if it empowers a multitude of regional support networks and centers to engage the public and decisionmakers at local scales—where decisions affected by climate are made on a regular basis. Fortunately, we do have examples of successful bridging organizations, such as the NOAA Regional Integrated Science Assessment program, which are university partnerships focused on supporting the use of climate information. As has been shown in multiple cases, products that are developed collaboratively between stakeholders and researchers are more likely to be “owned” and used by the stakeholders—so the process of network-building, though time-intensive, brings multiple rewards. But this network will have to be informed by a well-coordinated Federal science team—and the network itself will need to be well supported by Federal money.

Building Regional Capacity to Respond: Western Water and Climate Change

During the last week I heard the result of a large-scale assessment of public opinion: less than half of Americans believe that climate change is a serious threat, and even in California roughly half connect climate change with water supply problems, though water supply impacts may be the most critical aspect of climate change and California is in the grip of a large-scale drought. According to the Pew Center for People and the Press, only 30 percent of Americans consider global warming to be a priority. In a recent meeting in Arizona, water utility staff noted that their elected officials show very little interest in climate change, but water supply reliability is an issue that “keeps them awake at night.” Connecting the dots between cause and effect needs to be part of the “climate literacy” effort as we work to improve adaptive capacity.

Based on the findings of the International Panel on Climate Change, and the most recent reports from the U.S. Climate Change Science Program (CCSP), the water supplies of the west are seriously threatened by climate change. This is in part because higher temperatures alone have dramatic impacts on the hydrologic cycle—drying soils, reducing runoff into rivers, causing more evaporation from reservoirs, significantly increasing the demand for water for ecosystems, landscaping, power generation and agriculture. In addition to higher temperatures, recent climate model information suggests that the southern portions of the American Southwest and northern Mexico will also experience reduced precipitation. The result could be dire consequences for the Colorado River (the current best estimate by a team of climate scientists from universities all over the west is a 20 percent reduction in runoff by 2050). Given rapid growth, increasing demands for water, and the over-appropriation of Colorado River water rights, this prediction is not a happy one for the nearly 30 million people who depend on the Colorado.

But most water managers do not even know about the CCSP or the 21 Science and Assessment Products that have been developed in the last couple of years. It is clear that the 13 Federal science agencies that make up the CCSP do not coordinate with each other particularly well, and coherent messages regarding their work are not penetrating into arenas where they can best be used. If we are to have an effective and efficient climate science program and climate service, significant restructuring of the program will be required so that regional issues like water supply availability in the Colorado River basin can be addressed.

Ingredients of Successful Climate Services

- *User-centric problem definition*: to provide the most effective services, there must be an ongoing effort to identify the key decisions where climate information is needed, and to frame at least some portion of the Federal research program around those decisions. This does not mean that we should halt investment in basic understanding of the climate system; it does mean that we need to measure our progress in terms of improving our adaptive capacity, limiting risk, improving quality of life and building economic advantages by developing more problem-focused climate information.
- *Information at the time and space scales that decisions are made*: an important component of providing services that will actually be used is building a system that provides answers at the scale of decisions, for example, focused on reservoir

operations at the watershed scale. Resource managers across the board are frustrated that climate model projections are at such a large scale that they have little utility for actual decision-making. Although “downscaling” efforts are being initiated, including within my own research partnership, we are a long way from answering their questions.

- *Credibility of information*: A lot is riding on the decisions associated with climate predictions, in some cases billions of dollars in infrastructure investments; in other cases these decisions may make or break a family or a business. Users need to trust the source of this information. Trust comes from long-term relationships between scientists and decision-makers; building these relationships requires a long-term commitment of funding that is not tied to the politics of individual administrations.
- *Adequate funding and independent budget authority*: Because the problem requires building decision support infrastructure (training programs, data access systems, monitoring and assessment capacity, etc.), it does not lend itself well to an ad-hoc funding source that is based on the good will of individual decision-makers within the 13 Federal science agencies. There needs to be significant, centralized coordination with budget authority to ensure that structural support is built and that outcomes are delivered. There will also need to be priority-setting based on risk and vulnerability (among other considerations) and the process of priority setting will need to be de-politicized. Every sector and every region has needs, but we will not be able to meet all of the needs that are identified.
- *Clear leadership and authority focused on management for societal outcomes*: Because this assignment is so daunting and will involve so many people at various scales, there needs to be central leadership that is empowered to achieve outcomes that are valued by decision-makers and can cause agencies to engage through incentives and if necessary, through clear articulation of expectations at a high level. Leaders of this program will need to have the courage to take bold steps, including harvesting science outcomes that may not be viewed by some as “ready for prime time” and testing their utility for improving decisions.
- *Buy-in, coordination and engagement of Federal agencies beyond NOAA*: Although the roles of the various Federal agencies in the climate service have not been identified, NOAA clearly cannot and should not try to create the climate service on its own. Whatever coordination and management system is developed will need to provide incentives for all of the agencies to work together toward common goals. There is no time and no money for turf battles over the components of this system. NOAA will play a key role, but this project will require a variety of innovative partnerships with local and regional entities and universities as well as functional partnerships between Federal agencies. The capacity to do all of this coordination does not currently exist within NOAA.
- *A central portal for information (clearinghouse function/informatics)*: Because providing decision support that is timely, relevant and credible at a range of time and space scales will be very expensive, we must harness information technology to provide the tools that local, regional, state, tribal and sectoral decision-makers need. In many cases, providing better tools over the Internet and more useful ways to manipulate and visualize data may move us a long ways forward. Major investments are required in the “cyberinfrastructure” of the climate service. Significant progress is being made along these lines in the context of the National Integrated Drought Information System (NIDIS) and at the National Climate Data Center.
- *Adequate interface with communities, states, sectors, regions, tribes, etc.*: The engagement strategy needs to include ways to entrain, leverage and expand existing operational capacity (including the NOAA Regional Integrated Science Assessment Programs; science translation capacity within universities, including the Cooperative Extension Programs; natural resources management NGO’s and a variety of private sector interests, and local and regional jurisdictions and interest groups). This interface needs to be managed on an ongoing basis to ensure we are answering the right questions, that there is two-way communication, and that there is ongoing assessment of progress (in terms of both outcomes and process).
- *Capacity building and training programs*: Because there are few people who are qualified to do science translation for specific policy applications, a deliberate effort to expand the community of people who can tailor science information for specific applications is needed. This will involve partnerships with universities

as well as training programs for scientists, resource managers and elected officials.

- *Enhanced, strategic observation and modeling capability:* Despite my strong advocacy for more focus on engagement and decisions, there is a major disconnect between adaptation in regions and sectors and the types of monitoring that are currently underway. Although we have made great progress in remote sensing, and satellites can provide reams of new information at very useful scales, our ground-truthing capacity is totally inadequate. One of the biggest travesties is the disintegration of the USGS stream gage program at exactly the point in time when we need more and better gaging information. We also need more snow monitoring sites, more soil moisture measurements, etc. Strategic design of the monitoring program to focus on answering important management questions and to detect trends in real time is critical to better adaptive capacity.
- *Avoiding maladaptive decisions:* Many past decisions have increased our vulnerability to climate events (*e.g.*, allowing construction in floodplains and in low-lying coastal areas, subsidies for agricultural activities that increase demands for water and power without providing commensurate benefits, etc.). In the context of the stimulus bill we are engaging in building significant quantities of new infrastructure. A critical feature of adaptation is learning from past mistakes: let's make sure that this new infrastructure is designed for changing climate conditions, including using new engineering standards that recognize non-stationarity in the climate system and the already-evident increase in extreme events such as flooding, coastal erosion and storm surges.

Conclusions

By some accounts, the U.S. Government has spent more than \$30 billion in the last 8 years on climate science, and perhaps \$100 billion total. Given the magnitude of this investment, it is clearly time to take stock of what we do know, and though we haven't answered every question, empower decisionmakers to access and use that information with full understanding of its limitations. Improvements in forecast skill will always be welcome, but lack of skill is not the real reason that climate information is under-used. If provided with the tools to assess the quality of the information, and with access to "science translators," the resource managers of this country will make their own judgments about the types of information that could be useful to them. They are eager to have more tools at their disposal. Clearly we need to keep investing in research on both climate variability and on climate change—but it is time to get more value out of the investments that we have made.

Thank you very much for the opportunity to comment on this extremely important topic. After having worked on this subject for years, it is gratifying to see that we are on the brink of making significant progress in this arena and of joining forces with the rest of the world to limit the impacts of climate change through building adaptive capacity as well as by limiting this country's contributions to greenhouse gas emissions.

If you have any questions I would be very happy to respond.

The CHAIRMAN. Thank you very much, Dr. Jacobs.
Sean Dilweg.

STATEMENT OF SEAN DILWEG, COMMISSIONER OF INSURANCE, STATE OF WISCONSIN ON BEHALF OF THE NATIONAL ASSOCIATION OF INSURANCE COMMISSIONERS

Mr. DILWEG. Thank you, Chairman Rockefeller, Ranking Member Hutchison, and Members of the Committee on Commerce, Science, and Transportation.

My name is Sean Dilweg. I am the Insurance Commissioner for the State of Wisconsin, and I'm here on behalf of all the Insurance Commissioners for the National Association of Insurance Commissioners.

Today, I will focus on our position and perspective on the potential insurance-related impacts of climate change. I will also offer suggestions for insurance-regulator action to protect consumers and address insurance solvency, recognizing that climate-change-related risk continues to grow.

The insurance sector is uniquely positioned between the causes and the impacts of climate change. Last year, I chaired our Climate Change Task Force and spent a lot of time with industry and consumer advocates crafting a white paper, that was adopted by all of my fellow Commissioners, that is outlined and, I know, presented to the Committee, called “The Potential Impact of Climate Change on Insurance Regulation.” We have also been pursuing disclosure requirements on our insurance companies. This would be the first mandatory disclosure survey on any industry in the U.S.

I want to touch on a few different areas, and I’ll start by speaking to insurance investments.

It is imperative regulators examine how climate change will impact the investments insurers hold and establish applicable regulatory standards for investment practices of insurers. Direct and indirect investments in real estate represent a portion of all assets held by insurers. Many of these properties are located within coastal areas with increasing risk from climate-change-influenced weather perils, like hurricanes and flooding. As investors in these properties, insurers may be exposed to greater investment risk. Insurance regulators need to recognize the risk of weather-related losses on real estate is complex. It can arise, not only from declining asset values, but also the costs of fortification, physical damage to structures, and associated business interruption.

As regulators of one of the largest American industries, it is essential that insurance regulators assess, and, to the extent possible, mitigate, the impacts of climate change while encouraging insurers to incentivize sustainable practices. As such, insurers have historically played a role in the mitigation of losses. For example, as the result of fire disasters in the late 1800s, insurers led the effort to improve building codes and develop new building and loss mitigation techniques to reduce the effect of fire. You could say the modern-day city is heavily influenced by insurers. When you think about cities back in the late 1800s, you had a lot of wooden buildings, a lot of candles, a lot of gaslight. And finally the insurers just started saying, “Look, you need a fire station every five blocks. You need a water system put in place.” And that is what occurred, and that’s what we have today. Today, insurers can also help mitigate the impact of climate change by promoting the adoption of vigorous enforcement of uniform building codes throughout the Nation.

The task force heard from software developers on catastrophic modeling as it exists today. We heard from EQECAT and AIR Worldwide regarding the insurer’s ability to make the use of sophisticated catastrophe modeling. These models provided insurers with the ability to assess risk and price their products with a degree of accuracy. These models, however, only have a short-term focus—generally, 5 years or less. Climate change modeling, however, takes a much longer view—50 years or more—and attempts to evaluate the risk impact of gradual changes on climate, instead of measuring the risk associated with swift and severe events, as well as the frequency of those events. Our task force heard from the scientists working at the National Center for Atmospheric Research, where climate change modeling is evolving. In light of this, the task force recognizes that the science behind climate modeling

as it evolves is appropriate for the approach that regulators take with respect to climate change to evolve, as well.

We also pursued, this year, a forward-looking disclosure approach to provide investors, consumers, and regulators with eight reporting questions that will be phased in over the next few years. It represents a good first step in showing how the risks of climate change occur on our insurers every day. I expect this to be adopted by the NAIC next week.

It is clear to regulators that, whatever the cause, be it manmade or natural, climate change is occurring. From intensified hurricanes off the coast of Africa to the dryness or extreme wetness of a Midwest summer, climate change has an effect on our insurable interests, and thereby the companies and policyholders that each state regulates. The NAIC supports State and Federal tools to increase the accuracy of climate science as a basis for product pricing. It also supports increased climate science research funding to speed relevant climate change information to market.

We look forward to working with the Committee and Congress on this issue as the science continues to evolve. Thank you for holding this hearing and for inviting me here today. I look forward to answering any questions.

[The prepared statement of Mr. Dilweg follows:]

PREPARED STATEMENT OF SEAN DILWEG, COMMISSIONER OF INSURANCE, STATE OF WISCONSIN ON BEHALF OF THE NATIONAL ASSOCIATION OF INSURANCE COMMISSIONERS

Chairman Rockefeller, Ranking Member Hutchison, and Members of the Committee on Commerce, Science, and Transportation, thank you for the opportunity to testify today. My name is Sean Dilweg. I am the Insurance Commissioner for the State of Wisconsin and I am here on behalf of the National Association of Insurance Commissioners. In my testimony, I will focus on the NAIC's position and thinking on the potential insurance related impacts of climate change, I will also offer suggestions for insurance regulator action to protect consumers and address insurer solvency, recognizing climate change related risk continues to grow.

Let me begin first by stating that the most important duty of an Insurance Commissioner is to protect insurance consumers. It is the primary job of any insurance regulator to ensure that insurance companies remain solvent so that they can pay claims as they become due, and to ensure that insurance customers' and claimants' rights and interests are protected.

Investments

It is imperative regulators examine how climate change will impact the investments insurers hold and establish applicable regulatory standards for the investment practices of insurers. Direct and indirect investments in real estate represent a portion of all assets held by insurers. Many of these properties are located within coastal areas with increasing risk from climate change influenced weather perils like hurricanes and flooding. As investors in these properties, insurers may be exposed to greater investment risk. Insurance regulators need to recognize that the risk of weather-related losses on real estate is complex. It can arise not only from declining asset values, but also the costs of fortification, physical damage to structures, and associated business interruption.

Historically, and from a viewpoint of social construct, insurance has helped shape towns and cities as an essential financial security tool for individual and community economic development, with a corollary that availability and affordability are also essential. It is clear that loss mitigation and loss prevention are the most viable solutions to both current marketplace problems and the growing threat of climate change and global warming. It is the only way to moderate and reduce the incidence and severity of catastrophe events.

Accordingly, it is vitally important that insurers begin to assess and take into account the effects of climate change on all lines of insurance, from intensified hurricanes off of the coast of Africa to the dryness of a Midwest summer. Changes in

climate have a direct effect on our insurable interests and the companies and policyholders that each state regulates.

Mitigation

Insurance regulators must assess and, to the extent possible, mitigate the impact that climate change will have on insurance and encourage insurers to provide incentives for policyholders to engage in practices that will ultimately strive to limit losses. As such, insurers have historically played a leading role in loss mitigation efforts. For example, as a result of fire disasters, insurers led the effort to improve building codes and develop new building and loss mitigation techniques to reduce the effects of fire. Insurers in coastal regions are often leading proponents of better land use policies and mitigation efforts, such as roof strapping and storm shutters. Likewise, insurers can help mitigate the impact of climate change by promoting adoption and vigorous enforcement of uniform building codes. They can also promote building code upgrades and retrofits of existing structures by offering premium discounts for proven loss mitigation building techniques, and by advocating for lender or government sponsored low interest loans for these mitigation activities.

Some insurers have developed new products that provide coverage for green buildings. Fireman's Fund Insurance Company has introduced Certified Green Building Replacement and Green Upgrade coverage, a new coverage specifically for green commercial buildings that addresses the unique risks that come along with sustainable building practices.

CAT Modeling

The NAIC heard from several catastrophe modeling firms who explained how climate change factors into risk modeling techniques. Catastrophe models provide insurers with the ability to assess risk and price their products with some degree of accuracy. However, these models tend to have a short-term focus of generally 5 years or less, while climate change modeling takes a much longer view—10 years or more—and attempts to evaluate the risk impact of gradual changes in climate instead of measuring the risk associated with swift and severe events as well as the frequency of those events. The NAIC also heard from scientists working at the National Center for Atmospheric Research (NCAR) who indicated that climate change modeling is relatively new and still evolving. In light of this, the NAIC recognizes that as the science behind climate modeling evolves, it will provide better tools for companies and regulators and could increasingly factor into insurance decision-making.

NAIC Climate Change Task Force And White Paper

In 2007, the GAO reported that climate change was an emerging high risk area with long-term growth in exposure to private and Federal insurers but that the two sectors were responding, assessing and incorporating the potential long-term financial impacts differently. As an initial step in addressing the issue, the NAIC formed the Climate Change and Global Warming (EX) Task Force. The Task Force was charged with, among other duties, the responsibility of drafting a white paper documenting the potential insurance related impacts of climate change on insurance consumers, insurers and insurance regulators. The Task Force recommended its white paper, *The Potential Impact of Climate Change on Insurance Regulation*, and the NAIC adopted it on June 2, 2008.

In sum, the Task Force white paper discusses investment issues facing insurers and notes that some investment opportunities will arise. It encourages insurers to evaluate the geographic spread of the risks they are insuring and encourages insurers to develop contingency plans. The White paper also emphasizes the importance of greater disclosure. It encourages insurers to become involved in strengthening building codes and advocating for sound land-use planning and become more involved in loss prevention and mitigation. It also recognizes the impact of demand surge, post-event living expense increases, and issues with business interruption coverages and suggests that new solvency regulatory tools are needed.

The NAIC Task Force also provides a forum to bring together all interested parties for a transparent discussion and development of required information standards, innovative product ideas, and evolving technologies. The Task Force has been involved in a number of key efforts:

- Presentations by the U.S. Green Building Council (USGBC) on Green Building Standards and the environmental impact of building green. Topics included the impact of commercial and residential building on our environment; the environmental, lifestyle, and business advantages of building green; and information on USGBC's educational offerings.

- Discussions on innovative “Green” insurance products offered by Fireman’s Fund. Representatives from Fireman’s Fund, a subsidiary of Allianz, spoke about their variety of “green” insurance products, such as providing insurance coverage for certified green buildings and upgrades of traditional buildings following a loss, and a “green” homeowners policy (available to Illinois as of June 1, 2008 and many other states starting in July 2008). Homeowners products have taken a lead from the commercial products, and both have been well received in all regions nationwide.
- Presentation on CALSTRS Green Investment Strategy by its CEO, Jack Ehnes. Subjects included the incorporation of the United Nations’ Principles for Responsible Investments (PRI) that integrates active ownership and environmental, social, and governance issues into ownership policies and practices; the readiness, preparedness, responsiveness of the U.S. insurance industry for Climate Change; the current vagueness and lack of voluntary disclosure of climate risk; and requiring questions that would allow for better understanding of potential impacts on affordability of insurance and insurers’ financial health.
- A presentation on the California perspective on Climate Change by Lisbeth Landsman-Smith of the California Department of Insurance, and Max Moritz of Environmental Science, Policy, and Management, from U.C. Berkeley. Topics included development of a more comprehensive plan for handling the implications of fire hazards; refinement of Fire Hazard Severity Zone (FHSZ) mapping and a more risk-based approach; and an increase of equitability and reduction of uncertainties, in addition to assessing fees and research funding.
- The Climate Risk Disclosure Working Group met in Boulder, Colorado at the National Center for Atmospheric Research (NCAR) on September 11, 2008. During the meeting, the Working Group:
 - Heard from three scientists regarding current climate change research and modeling.
 - Heard a presentation from Risk Management Solutions (RMS) examining current hurricane model capabilities and reliability;
 - Discussed the August 15, 2008 draft *Climate Risk Disclosure Proposal*, including verbal comments from interested parties.
- Presentations from EQECAT and AIR regarding how climate is considered in hurricane catastrophe models. During the presentations the regulators:
 - Discovered that there are issues related to merging atmospheric data with historical hurricane data, particularly with projections in the 1–10 year range. To compensate, modelers are beginning to use multiple models with varying assumption methods (both historical and a blend of historical and predictive). However, the modelers agree that there will be relatively more intense hurricanes with more rainfall, with intensity increasing dramatically by approximately 2020.
 - Learned that modelers are less certain regarding projections about the number of hurricanes that will make landfall in the U.S. due to the conflicting hurricane scenarios between the Atlantic and Pacific Coasts.
- Presentation from Henry Fox (Fox Consulting) providing an update on the development of climate trend data. He discussed his research on historical weather trends in separate weather zones throughout the U.S. over a 50-year period in an effort to forecast future weather trends. His patented forecasting methods are unique in that they place a heavier weighting on more recent years. His findings suggest that some zones show increases in average temperature or rainfall while other zones show decreases. He did not believe his findings support the overall global warming theories. He suggested that his work could be used by the insurance industry and American businesses to better understand long-term weather-related risks in the weather zones examined.
- A presentation from 3C, a company that provides carbon neutral services, regarding how the European Union and U.S. carbon trading markets function. 3C also provided information to the Task Force about a joint venture product involving 3C and Allianz called, “Ecomotion.”
- Discussions on pay as you drive insurance.

Additionally, looking forward at 2009, we anticipate that the Task Force will look at hosting a possible climate change summit, and consider development of a guidance document aiding insurers in how they should respond to the *Insurer Climate Risk Disclosure Survey*, referenced below.

Disclosure

It is challenging for regulators to determine how well-prepared the industry is for the challenges of climate change. U.S. Insurers lag in SEC disclosure that relate to climate change. Only 15 percent of U.S. insurers surveyed discussed climate change in 10K filings, compared to 100 percent of electric utilities and 78 percent of oil companies. There was also a poor response to the Carbon Disclosure Project where only 30 percent of U.S. insurers responded, compared to 70 percent in Europe and 62 percent in the rest of the world.

The NAIC has taken a forward looking approach to developing assessment tools that identify the potential impact climate change has on insurers and how insurers are assessing those risks. The *Insurer Climate Disclosure Survey* is the first of its kind in any industry and could serve as a model for financial institutions to gain insight into the impact of climate change on their industries.

The *Insurer Climate Risk Disclosure Survey* is a mandatory public survey document that will be phased in over the next few years. It represents a good first approach to climate change so that regulators, consumers and companies can begin to understand how climate change is affecting the risks that are underwritten everyday. The *Disclosure Survey* is meant to be a starting point and the Task Force recognizes that as the science behind climate modeling evolves, so must the approach of regulators.

The *Disclosure Survey* standardizes climate risk disclosure information to make it easy for companies to provide that information. Given the infancy of this issue, the *Disclosure Survey* has been kept to eight general reporting questions for insurers that meet certain premium thresholds. However, it still provides some measure of transparency so that investors and regulators can better identify risks.

The questions seek general information from insurers about things they have done to reduce greenhouse gas (GHG) emissions in their operations, whether they have a climate change statement of policy, whether they consider climate change as they choose investments and what they have done to encourage policyholders to reduce losses caused by climate influenced events. Further questions delve deeper into insurer use of climate computer simulation modeling, analysis of climate change's impact on an insurer's investment portfolio and how the insurers are engaging their constituencies on the topic of climate change.

Insurance regulators believe this is the first step of many in assessing insurance industry efforts to measure the impact of climate change on insurer operations and policyholders.

Regulators also have a role to play in ensuring that environmental benefits claimed by insurers are authentic and reasonably quantified to lend validity to these efforts.

The NAIC supports efforts to increase the exactness of climate science as a basis for more accurate product pricing and in more climate science research funding to speed the delivery of relevant climate change information to market.

We look forward to working with the Committee and Congress on this issue as the science continues to evolve. Thank you for holding this hearing, for inviting me here today, and for your continued interest and leadership. I am happy to answer any questions.

The CHAIRMAN. Thank you, sir.
Mr. Alix.

STATEMENT OF FRANK ALIX, CEO, POWERSPAN CORP.

Mr. ALIX. Thank you, Mr. Chairman, for the opportunity to share my perspective on how science informs climate mitigation strategies.

My testimony today will focus on the importance of carbon capture and sequestration as a climate change mitigation strategy, the prospects for commercial deployment of carbon capture technologies on coal-fired power plants, and the actions the government can take to accelerate CCS deployment.

We all know that coal is abundant and cheap. It supplies 50 percent of the electricity in the U.S. and 80 percent in China. The economies of the Midwest, South, Southwest, and Plains States de-

pend heavily on low-cost electricity from coal. Therefore, CCS is the most important climate change mitigation strategy we can pursue.

According to the EIA, 36 percent of U.S. CO₂ emissions in 2006 came from coal consumption. Broadly deploying CCS with 90-percent capture efficiency could reduce those emissions to 4 to 5 percent.

Since the transportation sector accounts for another 34 percent of U.S. CO₂ emissions, transforming this sector with electric vehicles powered by low-carbon electricity could reduce our CO₂ emissions by another 20 to 30 percent. Therefore, CCS could potentially provide over half of the emission reductions required to meet our climate change mitigation goals.

Powerspan has been developing and commercializing advanced clean coal technology since 1994. Our approach to CO₂ capture is a post-combustion process designed to capture 90 percent of CO₂ emissions. The technology is suitable for retrofit to the existing coal-fired generating fleet and for new coal plants.

Pilot-scale testing of our ECO₂ technology began in December 2008 at FirstEnergy's Burger Plant in Southeastern Ohio, right across from Moundsville, West Virginia. The ECO₂ plant was designed to treat a 1 megawatt flue-gas stream and capture 20 tons of CO₂ per day. Initial testing has demonstrated 80-percent capture efficiency, which is a promising start. We recently completed two minor design modifications that we expect will increase the CO₂-capture rate to 90 percent.

The pilot plant was built using the same type of equipment that we plan to use in commercial systems. Therefore, successful operation of the pilot unit will confirm our design assumptions and cost estimates for large-scale CCS projects. Although commercial-scale CCS projects still have some risk, that risk is manageable, because the major equipment used in the ECO₂ process has been used in other commercial applications at the scale required for CCS.

Our experience in the emerging market for commercial-scale CCS projects supports our optimism. In 2007, Basin Electric Power Cooperative conducted a competitive solicitation for a post-combustion CO₂-capture technology to retrofit their Antelope Valley Station, which is a coal-fired power plant located in Beulah, North Dakota. The Antelope Valley Project will install CO₂-capture equipment on a 120-megawatt flue-gas slipstream taken from a 450-megawatt unit. Basin Electric has targeted 90-percent capture efficiency to provide 1 million tons of CO₂ annually for enhanced oil recovery. Six of the leading vendors of CO₂-capture technology responded to the solicitation. And after a detailed evaluation, Basin Electric selected Powerspan. This commercial CCS project is scheduled to start up in 2012.

Since being selected for the project, a feasibility study has confirmed that there are no technical limitations to deploying ECO₂ at the plant. The study estimated costs of less than \$40-per-ton for 90 percent CO₂ capture and compression. A similar study of ECO₂ recently conducted for a 760-megawatt supercritical coal plant estimates CO₂-capture costs of under \$30 per ton. A third engineering study focused on ECO₂ scaling risk determined that our pilot plant will provide sufficient design information to confidently build commercial-scale systems up to 760 megawatts.

Despite the promise indicated by the Basin Electric project, strong government action is needed to ensure timely deployment of CCS technology to support our climate change mitigation goals. Government action should focus on three areas: (1) a strong market-based cap on greenhouse gas emissions; (2) a CO₂ emission performance standard for new coal-fired power plants, and (3) early deployment incentives for commercial-scale CCS systems.

Incentives are needed to ensure early deployment of CCS, because CO₂-capture technology is not yet commercially proven and early CO₂ prices will not be sufficient to offset CCS costs. To be most effective, these incentives must provide long-term CO₂ price certainty to facilitate project financing and must be awarded competitively, preferably by a reverse auction, in order to minimize the costs while providing a market signal on the real cost for early CCS installations.

Early deployment of CCS technology will also create jobs and promote economic growth. These projects require 3 to 4 years to implement and create significant economic activity over their duration.

In addition, by incenting early deployment of CCS, the U.S. can assume a leading position in this critical technology sector and create a thriving high-tech export business, and the quality jobs that come with it.

In summary, CO₂-capture technology is commercially available from several qualified vendors with standard commercial guarantees. Independent studies show that early commercial installations of CO₂-capture technology are likely to be successful. The most important reason to promote early deployment of CCS is that post-combustion CO₂-capture technologies will preserve the huge investment in existing coal-fired power plants and allow us to use effectively the abundant low-cost coal reserves in the U.S. and in developing nations, even in a climate-constrained world.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Alix follows:]

PREPARED STATEMENT OF FRANK ALIX, CEO, POWERSPAN CORP.

Good morning, Mr. Chairman and Members of the Committee. Thank you for the opportunity to share my perspective on how science informs climate change mitigation strategies. My name is Frank Alix and I am CEO of Powerspan Corp., which is a clean energy technology company headquartered in New Hampshire.

My testimony today will focus on the importance of carbon capture and sequestration (CCS) as a climate change mitigation strategy, the prospects for commercial deployment of carbon-capture technologies on coal-fired power plants, and the actions the government can take to accelerate CCS deployment.

We all know that coal is abundant and cheap. It supplies 50 percent of electricity generated in the U.S. and 80 percent in China. The economies of the Midwest, South, Southwest, and Plains States depend heavily on low-cost electricity from coal. Therefore, CCS is the most important climate change mitigation strategy we can pursue.

According to the EIA, 36 percent of U.S. CO₂ emissions in 2006 came from coal consumption. Broadly deploying CCS with 90 percent capture efficiency could reduce those emissions to 4–5 percent. EIA predicts that CCS will have to provide at least 30 percent of CO₂ emission reductions needed worldwide to stabilize GHG concentrations in the atmosphere. Since the transportation sector accounts for another 34 percent of U.S. CO₂ emissions, transforming this sector with electric vehicles powered by low-carbon electricity sources could reduce our CO₂ emissions by another 20–30 percent. Therefore, CCS could potentially provide over half of the emission reductions required to meet our climate change mitigation goals.

Powerspan has been developing and commercializing advanced clean coal technology since its inception in 1994. Our approach to CO₂ capture, called ECO₂[®], is a post-combustion process for conventional power plants designed to capture 90 percent of CO₂ emissions. The technology is suitable for retrofit to the existing coal-fired generating fleet and for new coal-fired plants. ECO₂ is a regenerative process that uses an ammonia-based solution to capture CO₂ in the flue gas. Once the CO₂ is captured, the solution is regenerated to release CO₂ in a form that is ready for compression and pipeline transport for geological storage.

Pilot scale testing of our ECO₂ technology began in December 2008 at FirstEnergy's Burger Plant in Southeastern Ohio. The ECO₂ pilot was designed to treat a 1-megawatt (MW) flue gas stream and produce 20 tons of CO₂ per day. Initial testing has demonstrated 80 percent CO₂-capture efficiency, which is a promising start. We recently completed two minor design modifications that we expect will increase the CO₂-capture rate to 90 percent.

The ECO₂ pilot plant was built using the same type of equipment that we plan to use in commercial systems. Therefore, successful operation of the pilot unit will confirm our design assumptions and cost estimates for large-scale carbon capture and sequestration (CCS) projects. Although commercial scale CCS projects still have some risk, that risk is manageable because the major equipment used in the ECO₂ process—large absorbers, pumps, heat exchangers, and compressors—have all been used in other commercial applications at the scale required for CCS. The advanced technology in ECO₂ is innovative process chemistry. Commercial application of this unique technology holds no special challenges and therefore has a high probability of commercial success.

Our experience in the emerging market for commercial-scale CCS projects supports our optimism. In 2007, Basin Electric Power Cooperative conducted a competitive solicitation for a post-combustion CO₂-capture technology to retrofit their Antelope Valley Station, which is a coal-fired power plant located adjacent to their Great Plains Synfuels Plant in Beulah, North Dakota. Their synfuels plant currently hosts the largest CCS project in the world, with three million tons of CO₂ captured annually and sold for enhanced oil recovery (EOR) in the Weyburn fields of Saskatchewan. The Antelope Valley project will install CO₂-capture equipment on a 120-MW flue gas slipstream taken from a 450-MW unit. Basin Electric has targeted 90 percent CO₂-capture efficiency to provide an additional 1 million tons of CO₂ annually for EOR. Six of the leading vendors of CO₂-capture technology responded to the Antelope Valley solicitation and after a detailed evaluation, Basin Electric selected Powerspan. This commercial CCS project is scheduled to start up in 2012.

Since being selected for the Antelope Valley project, a feasibility study has confirmed that there are no technical limitations to deploying ECO₂ at the plant. The study estimated ECO₂ costs of less than \$40 per ton for 90 percent CO₂ capture and compression (in current dollars, with +/- 30 percent accuracy). A similar study of ECO₂ recently conducted for a new 760-MW supercritical pulverized coal plant estimates CO₂-capture costs of under \$30 per ton, including compression. A third engineering study focused on ECO₂ scaling risk determined that the ECO₂ pilot plant will provide sufficient design information to confidently build commercial scale systems up to 760-MW, supporting that ECO₂ technology scaling risk is manageable. Independent engineering firms led the feasibility, cost, and scaling studies for our prospective customers. As a sign of our confidence in commercial deployment of ECO₂ systems, we will back our installations with industry standard performance guarantees.

Despite the promise indicated by the Basin Electric project, strong government action is needed to ensure timely deployment of CCS technology to support climate change mitigation goals. Government actions should focus on three areas: (1) a strong, market-based cap on GHG emissions, (2) a CO₂ emission performance standard for new coal-based power plants, and (3) early deployment incentives for commercial scale CCS systems. Due to limited time, I will only elaborate on my third point, the need for CCS incentives.

Incentives are needed to ensure early deployment of CCS because CO₂-capture technology is not yet commercially proven and early CO₂ prices will not be sufficient to offset CCS costs. To be most effective, CCS incentives must provide long-term CO₂ price certainty to facilitate project financing, and must be awarded competitively, preferably by reverse auction, in order to minimize cost while also providing a market signal on the real costs for early CCS installations. Knowing actual CCS costs is extremely important to plant owners, investors, technology developers, and regulators in evaluating future investment and regulatory decisions. Competitively awarding CCS incentives is also consistent with how renewable portfolio standards are normally administered.

Early deployment of CCS technology will also create jobs and promote economic growth. CCS projects require 3 to 4 years to implement and create significant economic activity over their duration. For example, a single CCS project would cost between \$250–750 million in capital expense and create up to 500 jobs at its peak, with the majority of materials and labor sourced in the U.S. However the government's cost of the CCS incentive program would not be incurred until CO₂ sequestration begins upon project completion. In addition, by incenting early deployment of CCS, the U.S. can assume a leading position in this critical sector and create a thriving, high-tech export business, and the quality jobs that come with it.

In summary, CO₂-capture technology is commercially available from several qualified vendors with standard commercial guarantees. Independent studies show that early commercial installations of CO₂-capture technology are likely to be successful. The cost of widespread deployment of technologies such as ECO₂ appears manageable, particularly when compared to the cost of other low-carbon electricity solutions. And once we gain commercial CCS experience, future costs will no doubt decrease substantially.

The most important reason to promote early deployment of CCS is that post-combustion CO₂-capture technologies will preserve the huge investment in existing coal-fired power plants and allow us to effectively use abundant, low cost, coal reserves in the U.S. and developing nations, even in a climate constrained world. If we are not successful in commercializing CCS technology in the near-term, it will be difficult for the world to meet its long-term goals for climate change mitigation.

Thank you, Mr. Chairman. I would be pleased to answer any questions.

APPENDIX A

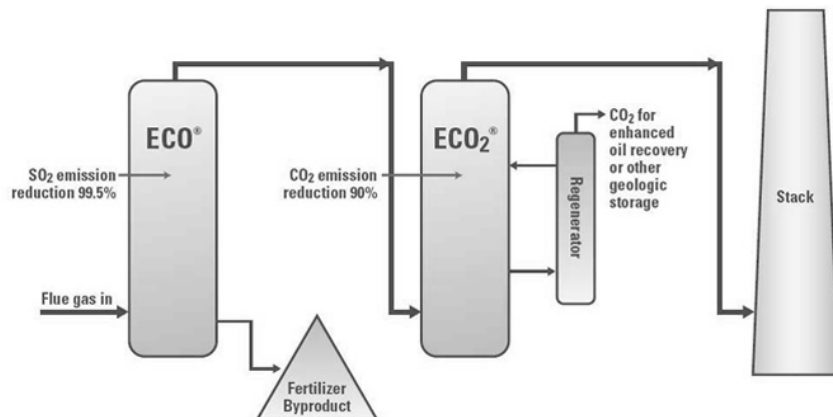
ECO₂[®] Technology for CO₂ Capture from Existing and New Coal-Fired Power Plants

Summary

Powerspan Corp.'s CO₂-capture process, called ECO₂[®], can be applied to both existing and new coal-fired electric power plants to capture 90 percent CO₂ from the flue gas. The process is designed as an add-on system that could be deployed when needed and is particularly advantageous for sites where ammonia-based scrubbing of power plant emissions, such as our ECO[®] multi-pollutant control technology, is employed. The technology is currently being piloted on a 1-megawatt (MW) slipstream at a power plant in Ohio. The ECO₂ pilot unit employs the same type of equipment that will be used in commercial systems. Because the innovation of ECO₂ is in its process chemistry, not in new industrial equipment, the risk in scaling from the pilot scale to commercial scale carbon capture and sequestration (CCS) projects is manageable. Commercial scale ECO₂ demonstrations (120–MW; one million tons of CO₂ capture annually) are planned to be online in 2012, with the captured CO₂ to be used for enhanced oil recovery operations.

Technology Description

ECO₂ is a scrubbing process that uses an ammonia-based (not amine) solution to capture 90 percent CO₂ from the flue gas. The CO₂ capture takes place after the nitrogen oxides (NO_x), sulfur dioxide (SO₂), mercury and fine particulate matter is captured using ECO technology or other air pollution control system. Once CO₂ is captured, the resulting solution is regenerated to release CO₂ and ammonia. The ammonia is recovered and returned to the scrubbing process, and the CO₂ is processed into a form that is sequestration ready. Ammonia is not consumed in the scrubbing process, and no separate by-product is created.



Incorporation of Powerspan's ECO₂® carbon capture process with the commercially available multi-pollutant control ECO® process.

Technology Development

Powerspan has been developing the CO₂-capture process since 2004 in conjunction with the U.S. Department of Energy (DOE) National Energy Technology Laboratory under a cooperative research and development agreement. In December 2007, Powerspan announced it exclusively licensed a patent for the process from the DOE. The patent granted to the DOE represents the only patent issued in the U.S. to date covering a regenerative process for CO₂ capture with an ammonia-based solution. Powerspan has conducted extensive bench-scale testing to establish the effectiveness of the process for CO₂ capture, and has made improvements to the subject patent. The testing has also established the design parameters for the ECO₂ pilot unit in operation at FirstEnergy's R.E. Burger Plant in Shadyside, Ohio.

ECO₂ Pilot Project

Commissioning was completed and ECO₂ pilot testing began at FirstEnergy's Burger Plant in December 2008. The ECO₂ pilot processes a 1-MW slipstream drawn from the outlet of the 50-MW Burger Plant ECO unit. It is designed to produce approximately 20 tons of sequestration-ready CO₂ per day while achieving a 90 percent capture rate. The pilot system is expected to run through 2009.

The ECO₂ pilot will demonstrate CO₂ capture through integration with the ECO multi-pollutant control process. Operation of the pilot will confirm process performance and energy requirements. The pilot program will also provide the basis for cost estimates while preparing the technology for the commercial scale CCS demonstrations planned to be online in 2012.

Scalability of ECO₂ to Commercial Scale Projects

Although the ECO₂ process is new and proprietary, the innovation is in its process chemistry. The equipment required for operation of commercial ECO₂ systems (e.g., large absorber, regenerator, heat exchangers, pumps, gas dryer, etc.) are commercially available at the required scale. Therefore, once the pilot scale demonstration of the ECO₂ process is completed, the scale up risk to commercial size systems is manageable. An independent engineering study focused on ECO₂ scaling risk determined that the ECO₂ pilot plant will provide sufficient design information to confidently build commercial scale systems up to 760-MW, supporting that ECO₂ technology scaling risk is manageable.

ECO₂ Commercial Demonstration Projects

Basin Electric Antelope Valley Station—In March 2008, Basin Electric Power Cooperative and Powerspan announced the selection of the ECO₂ process for a 120-MW commercial demonstration at Basin Electric's Antelope Valley Station located near Beulah, North Dakota. The selection of the ECO₂ process is the result of the first competitive solicitation process for a CO₂-capture demonstration at a coal-fired power plant in the U.S. The Antelope Valley project is designed to capture approximately one million tons of CO₂ annually which will be fed into an existing CO₂ compression and pipeline system owned by Basin Electric's wholly-owned subsidiary, Dakota Gasification Company. Dakota Gasification Company is the only company in

the U.S. that captures CO₂ from coal and delivers it for enhanced oil recovery operations. Since 2000, Dakota Gasification has been delivering CO₂ from its coal gasification facility, the Great Plains Synfuels Plant, to oil producers in Saskatchewan, Canada.

In June 2008, Powerspan successfully completed a feasibility study, which confirmed that there are no technical limitations in deploying the ECO₂ process at the plant. In January 2009, the project was approved for up to a \$300 million loan from a USDA Rural Utilities Service program for early CCS demonstration. Based on successful completion of detailed engineering studies and obtaining of necessary permits, the Antelope Valley project is expected online in 2012.

NRG Energy WA Parish Plant—In November 2007, NRG Energy, Inc. and Powerspan announced their memorandum of understanding to commercially demonstrate the ECO₂ process at NRG's WA Parish plant near Sugar Land, Texas. The 125-MW equivalent CCS demonstration will be designed to capture and sequester about one million tons of CO₂ annually. The ECO₂ demonstration facility will be designed to capture 90 percent of incoming CO₂ and the captured CO₂ is expected to be used in enhanced oil recovery in the Houston area. The Parish plant is expected to be online in 2012.

About Powerspan and ECO Multi-Pollutant Control Technology

Powerspan Corp., based in New Hampshire, has been developing and commercializing advanced clean coal technology since its inception in 1994. Powerspan's most significant technology success to date has been the development and commercialization of its patented Electro-Catalytic Oxidation (ECO) technology, which is an advanced multi-pollutant control technology to reduce emissions of sulfur dioxide (SO₂), nitrogen oxides (NO_x), mercury (Hg), and fine particulate matter (PM_{2.5}) in a single system.

For over 5 years, Powerspan has successfully operated a 50-MW scale ECO commercial unit at FirstEnergy's R.E. Burger Plant in Ohio. This unit has demonstrated that the ECO process is capable of achieving outlet emissions below current Best Available Control Technology standards for coal-fired power plants. The ECO process also produces a valuable fertilizer product, avoiding the landfill disposal of flue gas desulfurization waste. Furthermore, the ECO system uses less water because it requires no wastewater treatment or disposal.

In June 2007, American Municipal Power-Ohio (AMP-Ohio) announced its commitment to install our ECO-SO₂ multi-pollutant control technology on its proposed 1,000-MW American Municipal Power Generating Station in southern Meigs County, Ohio. In January 2009, AMP-Ohio announced the selection of Bechtel as its engineering, procurement and construction firm, and granted the firm a limited notice to proceed on the project. AMP-Ohio will use our ECO-SO₂ technology as an SO₂, mercury, and fine particulate matter control option for its strong environmental performance and potential to add our ECO₂ carbon capture technology.

APPENDIX B

Principles for CCS Incentives

1. *Competitive Award*: CCS incentives should be awarded competitively based on a reverse auction (incentives awarded to the low-cost bidders per ton of CO₂ captured and sequestered) for the following reasons:

- This would preserve the primary objective of a cap and trade program, which is to minimize cost of compliance, while also providing a market signal on the real costs for early CCS installations.
- Current climate legislation proposals, which arbitrarily set CCS incentive prices, would result in less cost-effective CCS technologies being subsidized, while plant owners/developers and regulators gain little or no information on what real CCS costs are.
- Arbitrarily setting CCS incentive prices would distort the market and support technologies that may not otherwise survive in a non-subsidized market. It would also create a windfall profit opportunity for the lowest cost CCS solutions and unnecessarily increase the cost of CCS incentives to the government.
- Knowing actual CCS costs is extremely important to plant owners, technology developers, investors, and regulators in evaluating future investment and regulatory decisions.
- Competitively awarding CCS incentives is consistent with how renewable portfolio standards are normally administered. Market participants—power sup-

pliers, regulated distribution companies, and state regulators—understand this process. States set a standard for the amount and type of renewable energy desired, and the potential suppliers respond to competitive solicitations to provide the renewable energy. The Federal Government could effectively implement the same type of approach for CCS projects/incentive awards.

2. *Long-term Price Certainty, Factoring in CO₂ Emission Allowance Value:* CCS incentives need to provide long-term price certainty and factor in the value of CO₂ emissions allowances because:

- CCS projects will likely be financed over 15 to 30 years. Current climate legislation proposals award CCS incentives over a fixed period of time (*i.e.*, 10 years) that is too short to finance most projects.
- CCS incentives would be most economical for the government if they factor in the increasing value of CO₂ emission allowances over time.
 - For example, if the CCS project developer needs to assure a price of \$40 per ton of CO₂ over 20 years to finance the project, the government could guarantee that price as an annual subsidy over the required term, after the value of avoided CO₂ emissions are subtracted. As the value of CO₂ emissions allowances rise, the amount of annual CCS subsidy the government is required to pay would decrease, while the project developer would still obtain the required price assurance to finance the project.
- As the value of CO₂ emission allowances rises over time, the percentage of allowance auction proceeds received by the government that are needed to support the CCS incentives will decrease.
- Current climate legislation proposals do not account for the added value of CO₂ emission allowances created by the CCS project or the fact that emission allowance values would be increasing over time. This approach creates a potential windfall profit opportunity for the early CCS adopters and unnecessarily increases the cost of CCS incentives to the government.

3. *CCS Project Size:* The primary objective of CCS incentives is to demonstrate CCS technology at commercial scale to accelerate market acceptance and deployment. In order to demonstrate CCS as commercially viable, a minimum project size criteria should be established:

- Experts such as MIT, DOE, and EPRI have established a minimum size of 1,000,000 tons of CO₂ per year for CCS projects to be considered “commercial scale.” Once the minimum CCS project size is met, preference should be given to larger projects.

4. *CO₂ Capture Rate:* In order to meet the objective of stabilizing GHG concentrations in the atmosphere, large stationary CO₂ sources will need to capture and sequester a high percentage of their CO₂ emissions (*i.e.*, ≥ 90 percent). Therefore, CCS incentives should establish a minimum standard for CO₂ capture (*e.g.*, 80 percent) and should favor projects that capture higher percentages of CO₂.

- Available technology from leading suppliers has shown the ability to capture 90 percent CO₂. Therefore establishing a minimum CO₂ capture rate as high as 80–90 percent is technically feasible and commercially acceptable.
- CCS projects will normally require 3–4 years to implement. An incentive program that encourages CCS to be demonstrated in sequential steps (*e.g.*, 50 percent then 80 percent) would unnecessarily delay deployment of the high capture rate CCS projects needed to combat climate change and increase the cost of CCS incentives to the government.

5. *Amount of CCS Incentives; Timing of Auctions; Technology Diversity:* The amount of CCS incentives in tons of CO₂ should be based on the following factors:

- The need to demonstrate CCS at commercial scale in a number of different configurations for both plant type and geological storage type. All large industrial sources of CO₂ should be considered equally. However, the government should not try to pick technology winners and losers. The primary driver in CCS incentive awards should be lowest cost per ton, with at least three different CO₂-capture technologies selected to promote technology diversity. This would facilitate the creation of a competitive supplier market of the most cost-effective technologies.
- The need to avoid early market responses to a CO₂ emission cap, such as a rush to gas-fired power generation, which may not be sustainable after CCS is com-

mercially proven and CO₂ allowance prices rise to where CCS would be deployed without incentives.

- The need to spread out incentives so that multiple CCS projects are awarded each year for at least 5 years as the current pace of technology evolution is great and the CCS incentive program should take advantage of and benefit from this rapid pace of improvement.
- The near-term need to stimulate the economy. CCS projects normally require 3–4 years to implement and create a great deal of economic activity over their entire duration. However the cost of the CCS incentive program does not begin until CO₂ sequestration is started upon project completion. For example, a 5,000,000-ton per year CCS project could cost \$750 million in capital expense to implement over the first 4 years. However, with a \$20 per ton net CCS incentive, it would only require government support of \$100 million beginning in year 5 and decreasing annually from there.

6. *Qualifying Criteria:* Projects that apply for CCS incentives should meet certain qualifying criteria. Qualifying projects should:

- Be new (existing projects that capture and sequester CO₂ should not qualify).
- Certify that they have all required permits or will have within 12 months of award.
- Certify that they have all required financing or will have within 12 months of award.
- Certify that they are scheduled to break ground within 12 months of award and have scheduled project completion within 4 years after ground breaking.
 - Projects that receive CCS incentive awards but are not able to complete permitting, financing, and groundbreaking within 12 months of award should forfeit the CCS incentive (but may apply again).
- Not be in any way disadvantaged by having received other types of government support such as loan guarantees, grants, and tax incentives.

7. *Sequestration Issues:* Existing CO₂ pipelines used for enhanced oil recovery (EOR) operations can support several new, large-scale CCS projects. The CCS incentives should be structured so as not to disadvantage these opportunities in any manner as they will likely be the lowest-cost and nearest-term projects available to demonstrate commercial scale CCS. However, in order to incentivize broader CCS deployment, the following sequestration issues need to be resolved:

- Legal and permitting requirements for geological sequestration including standards for measurement, monitoring, and verification (MMV).
- Long-term liability for sequestered CO₂.
- Incentivizing CO₂ pipeline construction at optimum scale. CO₂ pipelines benefit from economies of scale up to about 24 inches in diameter. This size would provide CO₂ capacity for 3–4 large-scale CCS projects (nominally about 15 million tons per year; equivalent to ~2,000 MW capacity at 90 percent CO₂ capture). Therefore preference should be given to CCS projects that create extra capacity by constructing pipelines or other infrastructure that could be used by multiple CCS projects.

The CHAIRMAN. Thank you very much.

I'll start with questioning, for 5 minutes, and we'll go in order, which will be Senator Hutchison, Senator Begich, Senator Kerry, Senator Snowe, Senator Klobuchar.

Dr. Killeen, is climate change reversible?

Dr. KILLEEN. Climate change over long periods is reversible. The Earth has experienced changes, that are natural changes, that have been large in the geologic record; however, in terms of the human experience, generations, we're going to be living in an era where the sea levels are going to be rising for centuries, and that—the global mean temperatures are going to be rising to some level that's going to be determined by our societal actions. So, reversibility on the time scales of societal decisionmaking is probably not on the cards. So, that's why we talk about smart adaption science,

because we are going to have to adapt to the changing circumstances that are already built into the system. And we talk about smart mitigation science, which speaks to the ultimate stabilization or least restrictions are the most severe outcomes that could occur over the next few centuries.

Returning—reversing to the pre-existing climate would require, not just reduced emissions, but going back to the concentrations of greenhouse gases in the atmosphere. And that's why mitigation science is actually—mitigation pathways are difficult, because it's not enough to reduce emissions—that slows down the process—you have to—

The CHAIRMAN. So, I take your answer—

Dr. KILLEEN.—deal with concentration.

The CHAIRMAN.—not to be yes, but to be no.

Dr. KILLEEN. No, in terms of practical considerations—

The CHAIRMAN. OK. Now, explain to me a little bit more why. Some people say that once you put carbon dioxide in the air, it's up there for 30 years; others suggest that carbon dioxide due to human activities stays in the atmosphere for 1,000 years. Now, I don't care which it is; it's horrendous.

Dr. KILLEEN. It's—

The CHAIRMAN. Why is it irreversible?

Dr. KILLEEN. It's actually both. The estimates are that about 20 percent of the carbon that's in the atmosphere due to anthropogenic human-induced emissions will reside sort of the order of magnitude of thousands of years. Other components of the reservoir will cycle more rapidly through the ocean and uptake in the land. There are some significant scientific questions about the degree to which the ocean and the land can continue to absorb as much carbon as they have been absorbing over the last century. That's one of the scientific questions that I allude to in my—

So, it's a—it is a complex, but not over—not impenetrable, set of scientific questions. We're dealing with a relatively simple molecule, three atoms. We're dealing with an atmosphere. We're dealing with a relative balance. The thermodynamics is pretty well understood. The residence times are dependent on a lot of factors, including weather factors. But, notably, the uptake of carbon by the living biosphere and the oceans—and there are some indications in recent papers that that may be plateauing, at least. So, there may be some diminution of the ability of the rest of the system to reabsorb carbon from the atmosphere.

So, when we're looking at long-term records, it's very important to crack that scientific problem. Where—how fast can carbon be taken back out of the atmosphere and stored in other repositories, in the ocean and in agricultural processes? And for how long will that carbon be sequestered there? There are some open scientific questions that need to be addressed.

The CHAIRMAN. My time's running out. You say 30 or 1,000, either one could be true. I talked, in my opening statement, about gaps in scientific knowledge. I'd like you to address that. We, the Commerce Committee, have jurisdiction over the National Weather Service; they have a lot to say about whether you're going to get a 20-percent drying-up of rivers in Arizona and other places in the

Colorado River. But, what is it that we don't know, scientifically, that we need to know?

Dr. KILLEEN. We need to know the rate at which carbon will be taken out of the atmosphere and absorbed in the ocean and in the land matter over the future decades. We need to know that number. It's a critical number for looking at the long-term outcome.

Right now—what matters is the concentration of greenhouse gases in the atmosphere; it's how many there are, how many molecules there are in the atmosphere. Every molecule plays a role in warming the planet. So, it's a quantity of carbon dioxide. That's controlled by two factors: emissions in and sinks out. And so, it's a balance between the emissions and the sinks. And right now, the average rate of accumulation of the quantity of greenhouse gases in the atmosphere is about 2 percent per year over the last decade. We need to get that number down. And that number is going to be a factor of both the emissions in and the sinks/sources out. And there are scientific uncertainties that we need to address, in terms of the role of the oceans, the Earth's oceans, which take up one-third, today, of the carbon that's put into the atmosphere is absorbed in the oceans—a full third of it—and that leads to ocean acidification—

The CHAIRMAN. Acidification problems.

Dr. KILLEEN. That's the acidification problem, yes.

So, the overall carbon cycle is fairly well known. I would say there are no "gotchas" or no surprises that are going to throw our whole theory out of the window. But, we need to fine-tune that understanding, particularly on the sink side. The emissions side is a function of economic development and the kinds of issues that my colleagues are being—are raising. The sink side, how fast you can take carbon out of the atmosphere, is a function of our understanding of ecosystem function and of oceanographic function.

The CHAIRMAN. Doctor, thank you very much.

Kay Bailey Hutchison.

Senator HUTCHISON. Thank you.

My question is for Dr. Killeen. If anyone else wants to jump in on this.

My area of interest, and actually, for the last two Congresses, I have introduced legislation on weather modification research. I'm told that we don't even have the data, for instance, where there is cloud-seeding in Colorado, if there is any difference in rainfall in Wyoming or Montana, and that that would be an area where, at least if we begin to track, that would be the basis of research. My original intention was to put it in NOAA, a weather modification research opportunity and tracking of weather, not only where you might have modification efforts, in the surrounding areas, in tracking the wind currents and directions, but also, for the future, to see what works and what doesn't. We're just seeing so much more of an intensity in our weather now than we have seen before.

My question to you is, do you agree that we need to have this kind of tracking and research? And where would you best place it? Is NOAA the right place? Or the White House Office of Science? Where would you say we would have the best traction for this kind of research?

Dr. KILLEEN. Well, let me first fully agree with you that this is a topic that's worthy of a research effort. As the planet warms, there are greater rates of evaporation from the world's ocean, there's more latent heat energy that is produced in the atmosphere, and there are greater levels of water vapor. So, the whole hydrological cycle is intensified. That means we get more severe weather at times. We get more evaporation, so we get more drought. It's paradoxical that we get more drought and you also get more severe—episodes of severe rainfall.

The system is intensified, and it—but, it's predictable, at some level. And I think today we don't know quite the level of predictability of rainfall and severe weather events in atmospheric phenomena. But, that's coming.

There was a big effort 30 years ago, as you know, to look at weather modification studies. And in some ways, that was premature, because we didn't have the observational tools at that time, we didn't have the polarimetric radar to look at the cloud condensation nuclei and their shapes, and to determine the physical processes that lead to precipitation out of clouds, the types of clouds. We now have those kind of capabilities—aircraft, radars, et cetera. So, we're much better positioned now than we were 30 years ago to really investigate the physical mechanistic processes that drive to severe weather events. And I—so, I think it is a very important area. And, of course, it's connected to climate because of this intensification of the hydrologic cycle that I alluded to.

Where it should be in the government? I think that the Federal agencies are interacting very well. There are experts in all of these Federal agencies who can appreciate this kind of project. Within the National Science Foundation, we have a place to go for research proposals dealing with this, and they will be effectively reviewed and funded when they come in.

I think what's needed is a stimulus to the scientific community that opens the door to new and pioneering, transformative research in this area.

So, I like the question.

Senator HUTCHISON. Do you think that the National Science Foundation would be the better policeman for where the research would go? Or, do you think NOAA should be that agency? How would you, if you were advising me on how to structure where it goes and if there is some added involvement by one or the other, where would you say?

Dr. KILLEEN. I would think partnerships are the right approaches. NOAA has more operational responsibilities and service responsibilities for stakeholders. NSF is the basic research organization, where our investigators can look at the nitty-gritty aspects of what certain types of clouds do under certain circumstances, can model the paths of the hurricanes, and so forth. So, I think it's a research-to-operations transition, and both agencies have their natural roles in that.

Senator HUTCHISON. I just have a couple of seconds left. Let me just ask you, if we start gathering the data, do you see a time when we could also do mitigation? If the science said a hurricane that is a level-2 in the Pacific, well, Atlantic, actually, off the coast of Florida, and when tracking, it turns into a 4 when it gets to Florida

and then on into the Gulf of Mexico, that, by having the research, there is a time at which we might be able to mitigate it out in the Atlantic Ocean so that it isn't a 4 when it gets to Florida or Alabama or Louisiana or Texas. Is that something that conceptually, that we might look forward to?

Dr. KILLEEN. That's beyond our reach today. It's probably beyond our reach in the next 10 years. But, I could—I could conceive of such kinds of things in the long term. As we further understand the nonlinear development of hurricanes—they develop, after all, from very small perturbations off the coast of Africa, often, and they—some of them grow, and some of them diminish. And so, I could imagine intervention—I could imagine it, intervention strategies, but I wouldn't want to even—

Senator HUTCHISON. I know.

Dr. KILLEEN.—imply that—

Senator HUTCHISON. We don't—

Dr. KILLEEN.—we're anywhere—

Senator HUTCHISON.—have the research yet,—

Dr. KILLEEN.—close to that today. Yes.

Senator HUTCHISON. —but, I would just hope that, if we start with research, that eventually we'll be able to go in that direction.

Thank you very much, Mr. Chairman.

The CHAIRMAN. Thank you, Senator Hutchison.

Senator Begich.

**STATEMENT OF HON. MARK BEGICH,
U.S. SENATOR FROM ALASKA**

Senator BEGICH. Thank you very much, Mr. Chairman. Thank you for holding this hearing.

And as the Senator from Alaska, I consider our State ground zero when it comes to climate change, as well as Arctic policy. There's a combination of issues in Alaska. And, you know, we see it firsthand. If it's from the north, with the Arctic melting, or in interior Alaska, where the permafrost is melting, or when you look to western Alaska, where villages have lost literally, several, several feet of land, or you go down to the southeast and you see the fishing area, with acidification of water. So, I have several questions, but I'm going to—

Dr.—is it Killeen? I have a couple of questions. But, as a good doctor, I want you to keep it short, only because we get only a few minutes. Because, Dr. Jacobs, I want to ask you some questions, because I'm intrigued by your testimony, because we, as policy-makers, sometimes get wrapped around the research and the science, and, I like to describe myself as “a mayor” which I have been, as “a mayor that just happens to be a Senator,” because, as a mayor, you have to be practical. And so, your testimony was very interesting to me, in a sense of that next step.

But, quickly, in your written testimony, you had some comments on permafrost in Alaska; 80 percent of its ground is permafrost, and the potential of, you know, the massive methane gas release, give me some commentary on that, if you can, and how you see that. I know you had some in your written testimony, but if you could verbalize that, I'd appreciate it.

Dr. KILLEEN. Yes, it's a very important study that needs to be done, intensive study of the permafrost, because there's a lot of, as you know, carbon contained in the permafrost.

Senator BEGICH. Correct.

Dr. KILLEEN. There's deep permafrost, which will reside for many eons, I'm sure, and then there's near-surface ground permafrost, on which homes are built, that can degrade quickly, and is degrading quickly.

There are some unknowns there, and there's scientific research that's needed to fully understand the rate at which permafrost is becoming degraded, and the rationale—the reasons for that.

And if you look back at ancient climate change, there's evidence that, in fact, temperature increases led the production of greenhouse gases, which would be a positive feedback effect. And so, there is concern that we need to fully understand the role of permafrost in the energy budget.

I would say the IPCC models that were used to produce the assessment did not include the effects of methane released in permafrost, so it's one of these missing gaps that the Chairman—

Senator BEGICH. It's another gap—

Dr. KILLEEN. Another gap.

Senator BEGICH.—in the research and science.

Dr. KILLEEN. Another gap. And—but, it's a very significant one that needs—and there are many researchers honing in that problem right now.

Senator BEGICH. Very good. And one last question, on research, in regards to acidification of the waters. And, you know, Alaska produces 62 percent of the natural fish stock for this country, and obviously we have about 25–30,000 people employed, directly or indirectly, in this industry. Can you give me any thoughts of where research gaps might be in regards to studying the impacts of acidification, not only from the science, but also from the job component?

Dr. KILLEEN. Yes, I think that's another very important area that needs much more work. The role of increased acidification on hard-shelled corals and phytoplankton is fairly well known, but what that means for the web of life in the oceans and the degree to which individual species will be responding over the decades is a big question. We know from our experience that some management strategies have worked for some fish stocks and have not worked for other fish stocks. And the scientific reasons for that difference are still to be determined.

So, I think there's an important area of oceanographic biology, which includes the whole ecosystem response to changed chemistry in the ocean, which is an important area of scientific research, as well.

Senator BEGICH. Great. Thank you very much.

Dr. KILLEEN. Were they short enough, Senator?

Senator BEGICH. That was very good.

Dr. KILLEEN. Thank you.

Senator BEGICH. Thank you. We get limited time here.

Dr. Jacobs, your testimony was interesting. And I did notice you smiled a little bit when a couple of folks were talking, because, probably as you know, I'm trying to hone in, on how we deliver the

message to the average individual out there, the voter, to understand the economic impacts, is how I've always portrayed it. Your testimony, written testimony, was very good. Can you if there are one or two things that we could do, as policymakers, to better communicate what the issue of climate change means to the average person, what would those be, from your perspective?

But, let me just say one thing, though, because I know most people, when you talk about emissions, they look at you with a blank eye, you know, they stare, they don't have any clue what you're talking about, anybody. So, give me your one or two hits that we would do.

Ms. JACOBS. Well, I guess I could start with an anecdote, which is a very brief one. You know, essentially, we were recently talking to some of the officials from the City of Phoenix, and they said, "Well, our city council really does not care about or understand climate change, but they do care about water-supply reliability, and it keeps them up at night." So, clearly the issue is connecting the science to the things that people really care about and the things that affect their livelihoods and their hearts. And so, clearly the landscapes they care about, the people they care about, and their source of—you know, their economic interests, are the ways to get to people. And, frankly, it's remarkable how few people have actually picked up on what's going on, given that it is happening all around us and the evidence is there.

Senator BEGICH. Yes, I'll leave on this question. It's one more for later, and I've run out of time. But, if you have not, or if you have, I'd be interested in maybe later letting my office know your response to. I know the U.S. Conference of Mayors has climate green page. Mayors have been very aggressive on this and kind of bringing it down to the street level. I'd be interested in what you see as good examples of how they have delivered the message. I know, as a mayor, what we've done, but I'd be very curious in your commentary on that. And not right now, but, you know, at a later time, because of time.

Ms. JACOBS. Thank you.

Senator BEGICH. Thank you.

The CHAIRMAN. Thank you, Senator Begich.

Senator Kerry.

**STATEMENT OF HON. JOHN F. KERRY,
U.S. SENATOR FROM MASSACHUSETTS**

Senator KERRY. Thanks, Mr. Chairman. Thank you for doing this hearing. It's really important.

Over the last 8 years, the emissions have grown at a rate four times faster than they did in the 1990s. And the fact is that every single climate change model that predicted what is going to happen, from the IPCC, the U.N. Panel, is now being exceeded. There was a recent study by Fletcher, MIT Heinz Center, that shows that if we take the best offering of every country in the world that has offered to do something, and if we were, in fact, to complete it, we would still wind up at about 550 parts per million, 600 parts per million, by 2050, which is well above what scientists tell us is permissible. Correct? As well as at a temperature of about 4 degrees—that's by 2050—it will continue up to 6 to 9 degrees by the end of

the century if we don't make changes. Is that a fair statement of sort of what the latest science is?

Dr. KILLEEN. Yes, sir, I think it—that's fair. There's some debate about what level is actually constituted dangerous interference with the climate, but there's a rough consensus about those numbers that you quoted, 500—

Senator KERRY. And previously, the science said, "Well, we can tolerate 550 parts per million." Then a few years ago they moved to 450 parts per million. And now the science is telling us that's wrong, we have to try to stay at 350 parts per million and hold the temperature increase to 2 degrees Centigrade. Is that accurate?

Dr. KILLEEN. I think most scientists would say lower is better. There are some practical issues with regard to where the stabilization point, in terms of parts per million carbon dioxide in the atmosphere, is. And I think that debate, which you're discussing, is raging. Where—what constitutes dangerous interference is the—

Senator KERRY. But, the problem is, if we get it wrong, it's catastrophic. If they're wrong and we've taken action, the best that we've done is improved health, responded to the environment, created jobs, improved our security by moving off of dependence on fossil fuels, and so forth. I mean, it seems—the balance in judgment of public policy falls on the side of caution and precaution.

Dr. KILLEEN. I would—if you're asking me—

Senator KERRY. Yes.

Dr. KILLEEN.—Senator, I would certainly believe, with my colleagues here, that we're going to be moving to a low-carbon economy, we should do it easily, readily, quickly, as fast as we could, to avoid the most severe consequences of these numbers. I should also say—

Senator KERRY. Let me follow up on something quickly, if I can, and I'm sorry to interrupt you, but I wanted to follow up with something that Senator Rockefeller said, because I won't have time to ask Mr. Alix a couple of questions.

Just very quickly, the 30 years to 1,000 years Senator Rockefeller was asking about, the 30 years, the variation depends, I assume, on the type of greenhouse gas, because what I'm led to understand is that the CO₂ that's up there has a half-life of approximately 100 years, 80 to 100 years or so. Is that correct?

Dr. KILLEEN. Yes, that order of magnitude.

Senator KERRY. And that means that whatever we put up there today is going to continue to do damage for the next 100 years.

Dr. KILLEEN. And a small component of it will continue to have interactions over the next 1,000 years, and that's where the 1,000-year number comes from.

Senator KERRY. The interaction—

Dr. KILLEEN. About 20 percent.

Senator KERRY.—is over 1,000 years.

Dr. KILLEEN. Yes. Yes.

Senator KERRY. But, the half-life of the gas, of the CO₂ itself is about 100 years.

Dr. KILLEEN. Yes. With—it's a mix of processes. There's a mix of sink processes. Some of them go faster than others, so you can—

Senator KERRY. Right.

Dr. KILLEEN.—you can consider it as not a simple one-answer problem—

Senator KERRY. I gotcha.

Dr. KILLEEN.—is what I'm saying.

Senator KERRY. So it's a variation based on the interaction of the gas, but there's no question but that it does that damage over the continuing period of time?

Dr. KILLEEN. Carbon dioxide in the atmosphere will have long-lived consequences of decades and hundreds of years.

Senator KERRY. Now coming therefore to your process, Mr. Alix, you're talking exclusively about a sequestration, a capture, that would then be made enough only for geologic sequestration?

Mr. ALIX. Primarily, yes.

Senator KERRY. There are four companies now doing non-geologic processing, taking gas, flue gas out of the flue, capturing 90 percent, as you've said, but transforming it into a calcium carbonate substance that can be used for construction. Are you familiar with that?

Mr. ALIX. Yes, I am.

Senator KERRY. Would your capture process lend itself to a similar, could it lend itself to a similar transformational non-geologic storage?

Mr. ALIX. I think once you have the raw pure CO₂, there are many things that can be done. In general, those processes, however, are limited by the amount of basic product that can be used and also locational issues, like proximity to seawater, issues like that. So we think those are exciting processes, but, in general, when you look at where coal plants are and the magnitude that needs to be addressed, sequestration, we believe, is probably 80+ percent of the answer.

Senator KERRY. Mm-hmm. And the sequestration, you're talking about compressing that gas,—

Mr. ALIX. Yes.

Senator KERRY.—correct?

Mr. ALIX. Yes.

Senator KERRY. By compressing it, does it stay compressed through the transfer process and into the sequestration or does it re-expand in the sequestration?

Mr. ALIX. It stays that pressure once it's put under ground.

Senator KERRY. It stays that pressure?

Mr. ALIX. Yes.

Senator KERRY. And how complicated is the transfer process into the sequestration?

Mr. ALIX. Well, my understanding is basically you have to characterize wells, you have to have pores, you have to know where it's going, and then there are 3-D monitoring techniques to see it.

Senator KERRY. How do you propel it? Through a pipe? How do you transfer it?

Mr. ALIX. Yes, absolutely, through a pipe.

Senator KERRY. What sends it? Pressure?

Mr. ALIX. Yes, and there are intermittent pipes for long pipelines. There are about 500–600 miles of pipelines going from Colorado to the Permian Basin for enhanced oil recovery. About 40 mil-

lion tons a year of CO₂ have been used over the last 20 years. So there's a great deal of experience in both.

Senator KERRY. This is the same process. We use this, I think, in the Dakotas, don't we? In North Dakota,——

Mr. ALIX. Yes.

Senator KERRY.—there's a process similar?

Mr. ALIX. Yes.

Senator KERRY. We've been doing the enhanced recovery out of that?

Mr. ALIX. Yes.

Senator KERRY. So this is built on that?

Mr. ALIX. Yes.

Senator KERRY. All right. My time is up. I appreciate it. Thank you for the process and thanks for your testimony.

The CHAIRMAN. Thank you, Senator Kerry. Senator Lautenberg was on his way back and he was one of the first people here, so when he does come back, I will call on him.

But now I go to Senator Snowe. Senator Klobuchar.

**STATEMENT OF HON. AMY KLOBUCHAR,
U.S. SENATOR FROM MINNESOTA**

Senator KLOBUCHAR. Thank you very much to all of you. You know, I come from Minnesota, and we believe in science. We brought the world everything from the pacemaker to the post-it note and we're very glad that in our state that science is upfront and center now again in the climate change debate.

I also serve on the Environmental Committee, so we've had a number of hearings with scientists, and I also was able to visit Greenland which many people call the "canary in the coal mine" for climate change. In an area that used to be covered in ice, people are now planting potatoes. Places that were covered in ice, we're able to land a helicopter on rock. So I saw firsthand the effects of climate change in one of our most poignant areas.

I also was seeing when scientists squelched what happens when the Center for Disease Control, the head of that, Julie Gerberding, her testimony was redacted in front of our Environmental Committee, and a lot of the things you talked about, the public health effects, Ms. Jacobs, were not able to come to light until a whistleblower actually came out and made those things known.

Again, I see hope in that we finally yesterday, Senator Snowe and I had a bill for a carbon registry, so that we can at least begin counting greenhouse gas emissions that the EPA actually just did with the wave of their wand yesterday that this is now beginning.

My question actually as we look at recently, we've heard, Dr. Killeen, about the potential for things, as Senator Kerry brought up, about things being worse than we thought and part of this is due to this idea of methane and what's happening with that, and I wondered, the methane gas that's sequestered in the Arctic permafrost and I know you mentioned this in your testimony and this is one of the reasons given that things might actually be worse than we thought in terms of global warming.

Could you expound on that a bit?

Dr. KILLEEN. Well, there are several indications that the pace of change is happening stronger than anticipated and sooner than an-

ticipated for reasons that relate to both emission rates which have gone up but also to the response of the planet and there are some things that are surprising to scientists.

For example, the Arctic sea ice in the Arctic Ocean has degraded much more quickly than the most sophisticated models would have predicted and so there's intense work going on to understand what's happening to the ice regions.

The permafrost area, I think, is one that really does require intense new work to measure the rates, to look at the pathways, et. cetera, and the other thing about potential changes, this is a complex planet, made up of interacting components, and science is struggling to work the details of that as a system.

It has many components: the ice, the air, the ocean, et. cetera, and we may have some surprises in store, and so there's a section of the scientific community that's really focused now on thresholds and potentially tipping points, things that might change.

If you look at the ancient record of climate, there have been events in the past, ancient past where rapid, relatively rapid change occurred, prehistorical times, and so there's a lot of interest in what might actually tip things out of the balance.

We're dealing with a semi-chaotic system, not a fully-chaotic system. It is—but it's not fully deterministic either in the sense that you lay out the equations and you know exactly what's going to happen. So dealing with that kind of a system opens the question of how fast and what is the range of responses that might be likely.

We don't today know the number which is the climate sensitivity of Planet Earth. If you doubled CO₂, what that planet would actually do. We know, we've got a good handle on the range of options and everybody looks at the median and says, well, that's where it is, but there are two tales, there's a slow tale and a fast tale, and we need to do a really good job of understanding how this planet is going to respond to these forcing functions.

So, yes, there's uncertainty on all of those fronts, but it does appear that the system is changing at rates that exceed what was in the IPCC kind of assessments.

Senator KLOBUCHAR. Exactly, and that's what they are saying themselves, that we're not going to have a new report when we go to Copenhagen, I don't think, from IPCC. We just know that it seems like it's worse than it is.

Dr. KILLEEN. There's a wonderful set of assessment reports that the U.S. Government has just produced. I refer to them in my—and I have a copy—

Senator KLOBUCHAR. All right. Well, we'll get that.

Dr. KILLEEN.—of these reports.

Senator KLOBUCHAR. OK.

Dr. KILLEEN. They contain the current cutting edge state-of-the-art on many of these areas.

Senator KLOBUCHAR. Ms. Jacobs, I just wanted to ask one more thing and that was that, Dr. Jacobs, you talked about how less people understand, and I guess I look at it a different way.

When I first started talking about this issue, you know, it was only kids with penguin buttons that would come up and talk to me and it has really changed as, you know, city councils in little towns, like Lanesboro, Minnesota, are changing up their light bulbs,

snowmobilers worried about it because they've seen the effects, barge owners worried because the levels in Lake Superior are down for the most part at lower levels than they were in the past 80 years.

And I appreciated Senator Begich's question, but I think your survey that you cited indicates that only 30 percent of Americans considered global warming a priority. When you think about the economy and the way it is, I actually do think that's not that bad of a number, and I know it's frustrating for you, but I tell you there has been a transformation and part of it is having a President that is putting this out there and talking about it, and the other part of it is talking about this in a way where we see the economic opportunity but also the economic safety net in how we do cap-and-trade and other things to make sure that it's done the right way and that it incorporates all of our energy sources, as Mr. Alix was talking about.

So do you at least acknowledge that there has been a transformation in that more people are aware of this and seeing it as a problem, even though it's not quite where you want it?

Ms. JACOBS. There's absolutely no question that we are in the midst of a transformation in terms of people's understanding, but I've been working with water managers on this topic since the late 1990s and though I think awareness is very much there, the ability to actually embrace the science and know what to do about it is not there.

So we have a lot of people very motivated to try to respond but many who really don't know exactly how to.

Senator KLOBUCHAR. Exactly. Well, very good. Thank you.

The CHAIRMAN. Thank you. As I indicated earlier, Senator Lautenberg was first here and therefore I call on Senator Lautenberg.

Senator LAUTENBERG. Thank you, Mr. Chairman.

The CHAIRMAN. Senator Thune, you will be next.

Senator LAUTENBERG. And I'm pleased that this hearing is being held. The fact is that this Committee, and I think you said it very clearly, has a significant role to play in the climate change and certainly our interest is very valuable and absolutely the right thing to do.

What we've seen thus far tells us a lot, so much about the threat that is imposed by global warming. I sit on the Environment Committee and also they're pursuing an interest in what's happening and what we've seen is the Antarctica getting warmer. I've been there. I've been to the South Pole, been up to Greenland, and when we look at the volume of sea ice that has disappeared, over 40 percent, it is frightening.

As ice melts, the sea levels could rise as much as 20 to 80 inches by the end of this century, and while in other states, Ms. Jacobs, obviously you're seeing the problems with water there, what the climate change portends for Arizona and similar states, the crucial science of global warming, tracking ocean temperatures, reading atmospheric data, does fit significantly in the hands of this Committee.

And one—there's a particular focus that we have here and that is that one-third of the greenhouse gas emissions come from the transportation sector which this Committee has a significant role

in and rail travel will be one of those solutions, and we know that moving travelers and goods by rail uses substantially less energy than moving them by cars or trucks. For example, a ton of freight can be moved over 400 miles on a single gallon of gas. Well, what does that do for the environment? Enormous things because it reduces some of the truck traffic and certainly automobile traffic if we continue to do that.

So our Committee's got to keep working to make passenger and freight rail part of the solution for our ability to make a difference in greenhouse gas emissions.

Now, Ms. Jacobs, what is the problem, as you see it, on the water side in your state and neighboring states, the challenge that's raised there?

Ms. JACOBS. Well, we have multiple challenges. One of them has to do with just temperature increase alone. When you increase the temperature that increases the evaporative rate. You lose a lot of moisture from the soil. All of the plants take more water, the people take more water. It takes more water for energy to cool houses and so forth. So we have both a supply side problem and a demand side problem with temperature alone.

What we're understanding now for the first time really is that there's an emerging consensus that we'll actually see reduced precipitation as well as increased temperatures and that combination is actually scaring people quite a bit.

We don't necessarily expect to see that across the whole country, but there is an area in the Southwest and Northern Mexico where it looks like most of the climate models are anticipating reduced precipitation. So there's a lot to be concerned about, particularly with reliability of service water supplies.

Senator LAUTENBERG. I see the threat of global warming as similar to the plagues that mankind experienced and I call this the 11th Plague and when I look at my grandchildren and concerned about their lives, they're very young now, it has me saying why haven't we not paid—raised a question about why have we not paid more attention to this at an earlier stage, but, nevertheless, we are where we are and the question is are the goals that we want to attain realistic and typically those who argue the other side of this say, well, the cost of jobs is an unacceptable cost, but there is a trade-off.

The fact is that there are jobs to be obtained as a result of the transition to a greener society, to the meeting standards that satisfy our need for work as well as our need for a better environment, and I ask, Dr. Killeen, at some point to the fact that regions, some regions are experiencing cooler weather than they normally have and as opposed to elements that were a sign that we are not really experiencing global warming.

What about the science behind this and why cooler temperatures in some places prevail?

Dr. KILLEEN. If I can respond, I think that's related to the fact that 2008 was only the 10th warmest year on record rather than the first or second. So 2008 was relatively cool and we've been in a relatively plateau in terms of the warming trend, but if you look at any of these 10-year cycles, you can find periods when you have relatively colder temperatures.

The 2008 period was marked by La Niña, the opposite of El Niño, which tends to cool the—so there’s nothing inconsistent with the recent temperature records and the global climate change theories that are couched in the IPCC documents and certainly the modern models. So there’s no sense that the—actually, in fact, everything that’s happened in the last 5 years has reinforced the understanding that was assessed in the IPCC.

Senator LAUTENBERG. Mr. Chairman, I assume we’ll keep the record open and that we’ll be able to—

The CHAIRMAN. We hope to have a second round. Thank you, Senator. Senator Thune.

**STATEMENT OF HON. JOHN THUNE,
U.S. SENATOR FROM SOUTH DAKOTA**

Senator THUNE. Thank you, Mr. Chairman, and thank you for holding the hearing. Thank you to our witnesses today for their insightful testimony. This is a complex set of technical and practical challenges that we have to face, and I think as policymakers we certainly want to be in a position where we’re making decisions that are based upon the very best science and the very best data.

A lot of proposals to cap and/or reduce carbon emissions are going to have a significant cost to our economy and going to impact individuals’ lives every day and so the stakes are pretty high and it’s important that we get as accurate information about climate change and its potential impact on our country and around the world as we possibly can.

I’m particularly interested, Mr. Alix, in some of your testimony and the technologies that you have developed that deal with carbon capture and sequestration and the role that those are going to play in our future energy supply, and I would be curious in knowing perhaps if you could respond to this question: what are the primary regulatory challenges to implementing the carbon capture and sequestration on a wide-scale basis?

Mr. ALIX. I think we have the classic chicken-and-egg problem where technology developers say that it’s commercially available technology for CCS which means we’ll sell it with commercial guarantees, but plant owners cannot point to any commercial installations that are operating.

So there’s risk. It’s a fair statement and so what we would say is, as happened previously with things like catalytic converters on our automobiles, the acid rain provisions in the Clean Air Act, you have to regulate and you have to have some faith in the technology providers to bring this forward, commercialize it and then drive costs down because no doubt, as we build the larger units and get experience, costs will come down.

The studies by engineering firms all suggest that we should have a high degree of success and one of the firms that operates in your neighborhood, Basin Electric Power Cooperative, is not only doing it successfully at the Great Plains Synfuels Plant, and sending its CO₂ up to the Weyburn fields but is looking at building the NextGen plant in South Dakota and capturing CO₂ and using it for enhanced oil recovery.

So there are a number of sophisticated owners who are ready to step forward and install this technology not only on existing plants but new plants.

Senator THUNE. We do have an exciting project in Selby, South Dakota. Basin Electric has proposed a 700-megawatt pulverized coal power plant with post-combustion carbon capture and sequestration and Powerspan's technology may prove instrumental in making that project a reality.

When it comes to the issues of siting, permitting, and other issues, are there things that can be done at this level that would help expedite those types of projects, and are there significant differences when it comes to transporting CO₂ from natural gas or other forms of pipelines, if you're going to get it to some place where you could put it in the ground and store it? What sorts of issues does this create? What kind of regulatory certainty is it going to take for folks to invest in these technologies?

Mr. ALIX. Well, clearly, a cap on CO₂ emissions, some sort of new performance standard on coal plants gives the owners the idea that you will be regulated for CO₂ emissions at some point. So those, I think, are important drivers.

When you get into actual implementation, pipelines that carry CO₂ for enhanced oil recovery, what we expect to use, either at a gas plant or coal plant, should be the same because the CO₂ itself is quite pure, quite dry, no matter where it comes from. So it's a carbon steel pipeline.

There's an optimum size in general to deploy due to economies of scale and generally you'd like to put a big pipeline in the ground that would carry CO₂ from multiple plants instead of each plant having a smaller pipeline. So there are some issues there.

In general, we look more toward enhanced oil recovery because those sites will pay for the CO₂ early on. They're well characterized. The processes and rules are in place. The longer term, I think, a set of standards which the EPA has started to develop in their water standards for sequestration, some measuring, monitoring, verification rules that are broader for not only oil fields but saline aquifers, coal seams, et cetera, those rules have to be promulgated by the Federal Government.

They have to include enhanced oil recovery which they don't currently and while that's in process, I think the fact that those aren't in place and that there's no clear long-term liability, I think, determination who will take ownership in the decades and millennium to come, I think those are some of the issues that also have to be resolved.

So in the near term, we think enhanced oil recovery is the way to go. The rules are there. But long term, there are standards that have been developed by some states, like Texas and Illinois, that on the Federal level would be helpful.

Senator THUNE. OK. And to get those on the Federal level, the agencies have that authority. Is that something that Congress would have to direct them to do?

Mr. ALIX. I understand today agencies have the authority on requirements to put CO₂ in the ground. In terms of liability, I understand that would have to be handled by Congress.

Senator THUNE. Right. OK. That would be a role that we could play, Mr. Chairman, in this process. I see my time has expired. I have some other questions but perhaps I'll submit those for the record.

Thank you all very much.

The CHAIRMAN. Stay around. Thank you. Senator Udall.

**STATEMENT OF HON. TOM UDALL,
U.S. SENATOR FROM NEW MEXICO**

Senator UDALL. Thank you, Senator Rockefeller. Thank you very much for holding this hearing. These witnesses have been very, very helpful and I look forward to a lively exchange with them.

When Senator Begich asked the question, you know, how do you talk to the average citizen about this issue. I'm from New Mexico. You mentioned in your testimony that we're going to see less precipitation, at least that's what the models show, and I've taken that less precipitation, changing our water, those kinds of things and tried to talk specifically about that, and one of the ways to do that is they have these models of where your particular state would reside in terms of the climate and it's very simple.

You can click on your state and for the case of New Mexico, you would drag New Mexico, imagine your mouse and clicking on New Mexico and drag it 300 miles to the south which would put us way down in Chihuahua, Mexico, and if any of you have been to Santa Fe, New Mexico, and then Chihuahua, you know there is a huge difference in terms of climate and it shows the dramatic change that would occur with our snow pack, for example.

The snow pack for the City of Santa Fe provides 40 percent of the water out of reservoirs and the outflow from the mountains. So if you change that dramatically where you don't even—you don't have that outflow or if it's significantly reduced, you then have to find the water some place else. We're mining our aquifers. We're not doing that on a sustainable basis and so we run into a very, very difficult water situation.

On top of that, you have the forests, which the trees get drier when you have less precipitation and you have more forest fires and these are the kinds of things that I think resonate with people and I wanted to, first of all, ask you the question of how reliable are these models and what I'm talking about in terms of mid-term because there's a question I want to follow up with, but just your general sense of how reliable are these models of what I'm talking about because I'm saying is the middle-term or the mid-area in terms of the model, and my understanding is the science is saying we're accelerating, we're going beyond the middle conservative increase we expect in temperature and we're going well beyond that.

So could you all comment on that, any of you that care to?

Dr. KILLEEN. Yes, Senator. I think the models that we have, the state-of-the-art climate models that we have today do not have the fidelity and the credibility at the regional or at the decadal level to really take those numbers to the bank.

On the other hand, the global-scale predictions are robust and credibility, and I think in my testimony, I was trying to make the point that we are poised now to move into this new era where, indeed, we can generate the kinds of models that will be meaningful

to dam providers, to agricultural, to city planners, et cetera, in exactly the kind of issue you're talking about with detail and with probabilistic distributions that you can actually make decisions on the basis of, and I think that's the exciting new scientific era that's dawning right now and is going to be driven by human capital, by interdisciplinary expertise, by computational and by a focus on the regional aspects of global climate change which then brings in this interface between science and the stakeholder community.

So we're on the verge, I think within a decade, of being able to do the kinds of things that you're talking about.

Senator UDALL. The time-frame you're talking about is a decade for these next generation predictive models to be able to be—

Dr. KILLEEN. Yes, sir.

Senator UDALL.—more reliable in terms of regional effects?

Dr. KILLEEN. You're seeing the infant, the first blush capabilities that have some capability and are clearly consistent with the global perspective, but the next level is going to be more detailed and much higher fidelity.

Senator UDALL. Thank you.

Mr. DILWEG. Senator, if I could follow up, as the insurers look at it, they are about 10 years away. I think the issue for them is they have these 50-year, 100-year looks and what insurers look for is more of a 25-year mortgage, 30-year mortgage to really shrink it down and identify it.

When you look at the wildfire modeling in California, that's almost there. That's probably going to translate on where you put your brush, where you put plants next to a home, things like that, but it is what you're seeing.

I mean, the concern is if you get a drought like what China is seeing, in your state, I mean that's catastrophic, and what we see in our region, it's not only the coastal areas, but it's—you know, in Wisconsin and Iowa, we've had the most rainfall in over, you know, 500-year floodplains. So it's these extreme swings that the insurers are trying to get a handle on and record tornadoes last year.

So I think I would agree on the commercial side that we're looking at about 10 years from now.

Senator UDALL. Thank you.

The CHAIRMAN. Thank you very much. Senator Warner.

**STATEMENT OF HON. MARK WARNER,
U.S. SENATOR FROM VIRGINIA**

Senator WARNER. Thank you, Mr. Chairman, and I'm still trying to master how you're in three places at one time, and I apologize if some of my questions may have been asked, but I'm particularly interested in following up with Mr. Alix.

I have a state like the Chairman's and I understand Senator Thune asked some questions on this subject, as well. I'm very, very interested in the possibilities around sequestration technology and, Mr. Alix, interested in what you're doing with Powerspan.

I would note that, like the Chairman, our states are very similar in terms of coal-producing and I would add very quickly that Virginia Tech has some of the most advanced sequestration research going on and it might be a place that you might want to visit, as well.

I am interested in your technology. If you have looked and costed out how much it would cost to put in your technology and can it be put into an existing pulverized coal plant and if you were to put in the technology, what type of output reductions would you see? I understand we clearly would get cleaner emissions, but what is not only the front-end price but what is the ongoing price in terms of decreased production?

Mr. ALIX. Well, as you point out, there's a difference between a new coal plant and a retrofit. We have looked at several retrofits and when we've looked at retrofits, we're typically looking at something on the order of baseload 500–600 megawatts, relatively new maybe mid-1980s on. So it has useful life remaining to amortize the investment, and we see costs of roughly \$30 to \$35 a ton for CO₂ capture and compression.

Typically, one would add another \$5 to \$10 per ton CO₂ for sequestration, unless it was sold for enhanced oil recovery, at which point you would have a decrease in that cost. So we think it can be installed and retrofitted. We think the costs would add on the order of maybe three to four cents a kilowatt hour in a retrofit situation, so it's not insignificant by any means.

In terms of the question—I'm sorry.

Senator WARNER. In terms of the retrofit and in terms of the new build, you know, whole in versus electrical production out with the technology, what decreased amount of—in fact, productivity, electrical productivity are we—what is the second half of the cost in terms of productivity?

Mr. ALIX. Well, these numbers take into account that cost, of course, but for a new plant, we see 15 to 20 percent reduction in net output and for a retrofit, it would be more like 20 to 25. Again, there would be efficiency-related losses and the cost of adapting it to a retrofit would be greater than a new plant.

Senator WARNER. Which is always less efficient. So it's quite significant, the reduction in net output for adding CCS, and I understand that Senator Thune asked a couple questions.

I was looking at it in terms of what can we do to speed development of this technology, Number 1, yours and other competitors, and I understand that the answers revolved around EPA standards and then dealing with some other liabilities.

Can you talk a little bit about some of the liability issues?

Mr. ALIX. Well, you know, I'm not extremely well versed on the liability issues because they're principally involved with putting CO₂ underground and maintaining it in place and not having any leaking or even sometimes earthquake potential if you put it near a fault. So there are people who are more well versed in that.

But in terms of how we get technology moving, soon because I think there's consensus we need to. There have been incentives proposed, both in the House and Senate as part of most climate packages, things like bonus allowances, that get CCS moving ahead of a CO₂ price that would pay for it, and we're a big advocate of that because we think that type of regime is needed to get 10 to 20 commercial scale units deployed in the U.S. and show that this is a viable response for mitigation to keep our coal plants running and to keep that low-cost electricity source viable.

Senator WARNER. The Administration—there has been a lot of controversy in the last few days about some of the numbers that might have been slightly cooked on the Future Gen project in Illinois and, you know, I'd like you to comment generally about the approach we're taking which seems to be still putting a lot of the eggs in that single beta site example rather than trying to support a series of beta sites around the country. Any comments anybody else on the panel wants to comment on the approach being taken?

Mr. ALIX. Well, clearly, there need to be a lot of different solutions, but the problem is existing coal plants in the U.S. and China which are pulverized coal plants. So I think that is the pressing need, both in the short term and the long term, clearly because these plants have oftentimes 50- or 60-year lives.

Beyond that, a new generation of technologies, such as Oxyfuel or gasification with CO₂ capture, is also promising for the decades beyond now and so at least one demonstration or two of each of those is critical for us to understand what the real costs are. So how one juggles those priorities, you know, I think is up to you all, but I would say that type of demonstration is important as is Oxyfuel, as is many of the post-combustion technologies of which we are only one.

But the big problem clearly is existing pulverized coal plants, both in the U.S., China, India, Europe, and Australia. That's where the emissions are and they're not going away any time soon.

Senator WARNER. Well, before I ask the panel if they want to comment, I know my time has expired, but I would simply add, putting the parochial hat on again, that we're about to build a next-generation plan in Southwest Virginia that has got, in effect, the land and the ability to do a sequestration demonstration project that I would strongly urge—and I for one think in the area of Appalachia that basically developed coal, that powered our economy in the th 20th Century, sure would be great if we had a couple of demonstration projects on how we're to be able to use coal in the 21st Century actually taking place back in our home region.

So I would urge you to consider that and again I know my time expired, but if anybody else wants to add a comment in terms of the approach the Administration is taking on this.

The CHAIRMAN. It's more than expired, Senator.

Senator WARNER. On that note, thank you, Mr. Chairman.

[Laughter.]

The CHAIRMAN. Thank you, Senator Warner. Senator Cantwell.

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

Senator CANTWELL. Thank you, Mr. Chairman. Thank you for this important hearing.

I'd like to ask Ms. Jacobs and Dr. Killeen about adaptation in general. Washington State and Seattle and King County, all three entities have done regional climate analysis for adaptation. So I think they're really kind of leaders in the country in doing that, and we really don't have the large-scale models.

Part of the issue of doing climate adaptation is that the models and data for the large-scale are so important to then give to the local entities so that they can make regional plans from them. We

did pass an adaptation bill out of this committee and unlikely to reintroduce it again this year because I think it's important that we have the impetus and Federal agencies are doing their part in planning, particularly when it comes to incorporating climate models and infrastructure and decisionmaking.

My question is what models are needed for the local governments and regional governments to appropriately plan, and why aren't we doing that right now? What do you think is standing in the way of why we're not—why we haven't achieved that goal yet on adaptation?

Ms. JACOBS. I'll start and then I'll pass it on. It isn't only because we don't have the models that local people are relatively frustrated. I mean, it's partly because it's very difficult to know how much uncertainty there really is and I think that if you explain clearly to people that, you know, it's true, we don't know exactly how much a plant's going to warm, we don't know how much sea level is going to rise, and we don't know exactly what's going to happen in the climate system, however, we know it will be warmer, we know that sea level will be higher, and we expect longer droughts and more extreme events.

Well, if you say that, then you know you need to, you know, really beef up your infrastructure, you need to be concerned about reservoir capacity, et cetera. There are a number of really distinct and sort of obvious responses to the higher temperature, the more extremes, et cetera. So a lot of people are getting wound up about not having the down-scaled information available to them and they really want it, and I understand that.

My research group is working on a down-scaling project right now, but I also am concerned that people want definitive answers and those definitive answers are not going to be available fast enough to suit them.

Senator CANTWELL. But shouldn't we have Federal agencies require taking into consideration these factors into their decision-making?

Ms. JACOBS. Sure. Absolutely.

Senator CANTWELL. We've added Washington State to 100-year floods back to back. So people are saying hmm. They're not really 100-year floods if they're back to back.

Ms. JACOBS. Yes. There's—absolutely. We need to be paying far more attention to adaptation and I don't mean by the fact that we don't need to have perfect information that we shouldn't be making decisions and we shouldn't be concerned.

We need to be concerned and we need to make decisions and we need the Federal agencies to be helping with that, both with producing the science and with doing those adaptation things themselves.

Senator CANTWELL. And putting that in the statute would help.

Ms. JACOBS. Yes.

Dr. KILLEEN. May I add to your question on the model—

Senator CANTWELL. Yes.

Dr. KILLEEN.—state of readiness? The models of the 1970s could barely have a stable planet to do any climate analyses. By the 1980s, you had the atmosphere and the oceans circulating and interacting. In the 1990s, you added things like carbon, et cetera.

The state-of-the-art model today has many of these interacting components but as a resolution element, there's a grid point like every 50 kilometers. So what you're looking for is not resolved in the current state-of-the-art models.

The next generation state-of-the-art model opens that door. You suddenly are able to look at one to two kilometer resolution. You can resolve large estuaries. You can resolve specifics about regional issues and those models will be running on super computers and they will have the methane and the ice shelves and all the missing ingredients that we've been talking about in this hearing and they will also have a family of adjacent models that are called, "integrated assessment models," that will be stakeholder-tuned to exactly do what you're referring to.

So we're on this threshold of really being able to do the kinds of integrated assessments and then interact with statutes and policy-makers in the next few years.

Senator CANTWELL. And that information probably would be better than just saying it's a 100-year flood, correct? I mean, it will be based on more science, more data, more information than just looking at one piece of the puzzle which is history on climate?

Dr. KILLEEN. Yes, that information—we won't just be redoing the tables of the 100-year floods but you'll be getting probabilistic distributions of likely outcomes by parameter, by region, by economic sector, and this is going to be of incredible use to the way society is managed.

Senator CANTWELL. I know my time is up, Mr. Chairman, but I'd like to submit a question to the panel about what research level we need on ocean acidification because that's another model that we need right away. Our shellfish industry is having unbelievable problems on feeding this year just because of the climate change. They need information. They need an understanding of what's happening, and I think people—the oceans are just at a much more rapid impact on the CO₂ than I think people realize.

I know the Chairman understands this issue. So I thank him for his patience and indulgence on it.

The CHAIRMAN. Thank you, Senator Cantwell. I'm going to make an effort here to have a second round and I want to pick on you three.

Commissioner Dilweg, you talked about last century and what you had to do with wooden houses having fire engines every five blocks. That's what the insurance industry said had to be done and it happened. So now you've got a new situation and so, in effect, I'm just drawn to ask you what kind of new kinds of insurance policies are you seeing or do you foresee being issued, promulgated or whatever to deal with our current situation?

Mr. DILWEG. I think the issue that we run into as regulators is, as the companies are innovative in their products, are they pricing it correctly? Are they taking into account climate change and then are they charging too much or not charging enough?

We don't right now have the tools to kind of check the industry on that, but I think some of the industry innovations surrounding miles traveled in an automobile, getting a discount for miles traveled, getting a discount for a hybrid, giving incentives, you have companies that are giving incentives to have leads-built and green-

built as you rebuild Galveston or Katrina, so those types of things are occurring and you're getting consumers willing to pay a little bit more and so the area that I see most recently the interaction of the insurance industry in two areas drove how we viewed the Y2K problem.

We started asking questions, and this is really the question, can the insurance industry drive the paper company or the coal plant to change, and in the Y2K situation it was the insurance industry and the SEC, for example, saying, all right, this is going to happen, what are you doing? Is your system going to shut down? Am I going to have to be paying business interruption insurance?

You know, Y2K was a very specific example where they chimed in, and then you look at safety in automobiles that has been a long-term process of—I mean, when I was a kid in the 1970s you didn't wear a seatbelt. I mean, you know, the windows went up on your head. You know, the automobile was a pretty scary place for a kid. Now, you're locked in a five-point harness. You've got air bags. You've got everything running at you.

The CHAIRMAN. I've got to cut you off and let the other two in.

Dr. Jacobs, can you give me an example of how you take science and then make decisions from it?

Ms. JACOBS. Well, that's a great question. I'll give you an example from my own research.

I've been working on the Colorado River and helping the Bureau of Reclamation with the decisions they make to operate the dams on the river system and helping them to incorporate both current ocean temperature information that has predictive capacity and think about the future in terms of the very long term what does climate change mean to the operations of the Colorado River and to the stakeholders that are dependent on it. So that's one example.

But the Arizona Water Institute that I have been running for the last 3 years exists entirely to connect the university system to the people who make decisions. So it's about mobilizing that information for people to use and so we focus on the stakeholders in the State of Arizona, answering water quality questions, salinity, energy and water, those kinds of issues.

The CHAIRMAN. Thank you. Mr. Alix, we had this thing called Lieberman-Warner, last year. It was a big environmental amendment and it said that by the year 2050, carbon dioxide had to be down to 30 percent, and in you walk and start talking about 10 percent and, I mean, this is stunning because I think if you went to 100 percent, it's totally cost ineffective. That's the question I'd like to ask you but don't have time to ask you.

If you could go to 10 percent or 8 percent or whatever it is and you suggested actually 9 percent, why aren't others interested? Why are some of the largest energy companies that do this, why are they sort of taking off on their own track which is much less effective?

Mr. ALIX. Well, I think, first, my comment was coal-fired power plant emissions could be reduced from about 36 percent to four to five.

The CHAIRMAN. Four to five?

Mr. ALIX. Four to five.

The CHAIRMAN. Good. That's good, because that's what Dr. Holdren said.

Mr. ALIX. That's great. I'm in good company then. Certainly transportation could be reduced, and then you look at homes and other uses and industries.

Overall, you know, the overall goal, I do think, you know, 80 percent reduction that the President has recently proposed is achievable by 2050 from my view. Why others are not quick to grasp it, it's difficult and it's costly and there's risk.

These are very large capital investments, you know, for carbon capture and storage on a baseload power plant, \$500 million or more. It's going to increase the cost to ratepayers two-three-four cents a kilowatt hour which for industries that depend on low-cost electricity in West Virginia and other places is a very significant hit.

The CHAIRMAN. The government could help pay.

Mr. ALIX. I think if the government subsidizes early units, which is part of the bonus allowance structure in Lieberman-Warner and Dingell-Boucher, I think it's a huge, huge reason for the coal industry to embrace it, and I think you're seeing certain folks in U.S. CAP and other places saying, you know, if the trade-off is the government pays for some of these early installations to show the technology's commercial and not disadvantage our low-cost plants, then we can get onboard.

The CHAIRMAN. Well, let the world take note of you, and now I'm going to infuriate the Governor, former Governor of Virginia if I continue, so I have to stop and ask Senator Hutchison.

Senator HUTCHISON. I just want to ask one question again of Dr. Killeen, if you know.

I have seen hurricane-tracking since, basically 1900s, maybe even a little before, but with the levels attached to it. So we have seen really an ebb and flow. It hasn't been just a continuation of a build-up through the years, but what I haven't seen, and I wonder if you have any knowledge of this or if there is tracking, is what seems to me to be a relatively new phenomenon which is the surges.

Katrina didn't hit New Orleans. It was the surge that really did the damage to New Orleans and Ike, the surge was something we have never seen. How hard but also how far in the coast it came. I grew up in Galveston County, so I'm speaking anecdotally, but I can't remember, after the sea wall was built, which is 12 or 13 feet, I don't remember that it was ever breached, but it was as if you could go and jump in a swimming pool when I was down there right after Ike. It was right there.

My question is do we have a record of that, and do you see a pattern there on the surge as opposed to the intensity of the wind?

Dr. KILLEEN. This is a very active and, I would say, not controversial but dynamic scientific discussion on how hurricanes have changed over time, and there's now literature on the relationship of the track, the intensity, and the storm surge consequences of hurricanes, and there's a group of scientists who are publishing results that look—that suggest that intensities of hurricanes have increased, not numbers of hurricanes because they're limited by the number of easterly waves that come off Africa.

So you have kind of a total number that we could never predict but the intensities of hurricanes and, of course, that relates directly to storm surge. So the pressure in the middle of the hurricane is what, when it hits landfall, is going to be the principal driving factor behind the storm surge. Also angles and things like that. But that's an active area of inquiry.

I would say where we have seen real progress is on hurricane track estimation. We're getting better predictions of where hurricanes are going to go further upstream than before. We're getting—we're making some inroads on intensity, as well, although that's a much tougher problem because you have to deal with wind shear in the atmosphere and other things, but if you fly aircraft in, you drop sounds, they're actually improving, too.

So we're getting better, and I would say that there's—the jury's out on exactly the relationship of hurricane prevalence and climate change, although there's a body of work that suggests that almost the intuitive thing is happening which means that you have more evaporation, you have greater energy in the system, and the hurricanes are going to be stronger. So there is evidence that has been published and there are people who argue against that, also.

Senator HUTCHISON. Well, I have seen the tracking be so much more accurate in the last few years. They have predicted exactly where these go and, of course, it helps in saving people's lives, but then the surge was not expected to do the damage that it did and did not really give the notice in Katrina and really they were not prepared for it in Galveston either and along the Gulf Coast for Ike.

As we are working toward the legislation that I'm hoping to introduce, I really want to make sure that I put everything in that we ought to be focusing on and I would look forward to having your help.

Dr. KILLEEN. I would be delighted to.

Senator HUTCHISON. All right. Well, thank you very much, Mr. Chairman, for the second round. Thank you.

The CHAIRMAN. Thank you very much. Senator Warner.

Senator WARNER. Thank you, Mr. Chairman. I'll try to be a little more observant of my time.

The CHAIRMAN. No, don't, because I've got a question after you.

Senator WARNER. I think you raised a very valid point with Mr. Alix, which is if we're on the cusp of an inflection point, why don't the traditional incumbent industries get it? And making one analogy from an industry I'm a little more familiar with and that was the wireless industry, the cell phone industry, you know, I was in that for a long time, co-founder of Nextel and I will always remember back in the mid-1980s, cell phones were just starting to develop, every bit of smart money, all of Wall Street and all of the telephone companies all had a common consensus. It would take 30 to 35 years to build out a wireless network in America and at the end of that 30 to 35 years, 3 percent of Americans would have cell phones.

Well, they totally got it wrong because we hit an inflection point, I think around energy and with the push of climate change, if we do it right, we are close to hitting that inflection point, and my question, probably directly to Mr. Dilweg, but again with the 3:48

I've got, anybody who wants to add on, is are there things, other than government incentives, and are there things, for example, that the insurance industry could do to accelerate this?

For example, I believe that until very recently people have become concerned about climate change, the American consumer has been basically told two options, you know, turn out the lights or go buy a Prius, and not much in between, and in the last year or so, we're starting to see movement with the development and perhaps more acceptance of EnergyStar and we've seen specific industries meet certifications.

But I tend to believe that we're still lacking across industry consumer branding Good Housekeeping seal of approval that might be EnergyStar on steroids so that consumers in all of their daily purchases have a trusted and more environmentally-sensitive climate change-sensitive purchase option versus a traditional which might again help us move in how consumers making better choices about how they get their power generation.

I guess I'd just be interested in seeing any comments from any of the panel beyond simply what we can do with governmental incentives, what we can do to move consumer choices, and are there things the insurance industry can do to help?

Mr. DILWEG. I think in the insurance industry, the main participants in this have been the reinsurers because when a primary insurer, you know, like a Liberty Mutual, blows through its limits, it's the reinsurer that picks it up. It's the reinsurers that are more adventuresome in Europe. They have to actually cover flood in Europe. Here, flood is covered by the Federal Government. So, you know, it's that—that's where I've seen the most, the embracing of climate change because they're on the hook financially.

As far as the kind of branding and getting into the products, that's slowly evolving. The ties are there. The consumers are starting to drive it. Some companies are doing it just to get the consumer approval, but it's not a cross industry type of thing at this point.

Senator WARNER. Dr. Killeen?

Dr. KILLEEN. Senator Warner, I'm not an expert on consumer preferences or anything like that, but I think part of the debate about climate science has been because the signal of humankind-induced changes has been masked to some extent by natural variability. That's now changed.

The signal for human-induced change has come out of the woodwork, if you like. Ten years from now, it'll be really out of the woodwork and so that's going to affect people's perceptions in substantial ways. So my daughter's generation and my daughter wants to occupy one of these seats, incidentally, but is already very passionate about it. The next one after that is going to be even more aware and so forth. So there will be the public attention is going to be really riveted by this story as it unfolds.

Senator WARNER. Well, I agree with that, and I think that there has been, while well-intentioned things like EnergyStar and lead certification, but the thinking has not been broad enough, expansive enough, and in many ways our challenges would be easier if we could really engage the American consumers in this debate in a bigger way.

Thank you, Mr. Chairman.

The CHAIRMAN. And in a more creative way. We obviously have to be so much more aggressive in putting—

Senator WARNER. Aggressive and more creative. We need something to make this user-friendly. Again, my daughters are in the same circumstance. They may not want to sit here but they want to be part of the solution set and we don't—every consumer choice this decision—this can be built in and there has not been a cross-brand, you know, really professionally-driven non-governmental approach to this and I think it's a wonderful opportunity.

Thank you, Mr. Chairman.

The CHAIRMAN. Thank you, Senator Warner. Two questions.

First is, Dr. Killeen, my understanding is that we talked earlier about permafrost, Siberia, Alaska, other places, under permafrost, and I don't know how much is there of it, is methane. Methane, I'm told, is about 30 to 35 times worse than carbon dioxide.

So my question to you is, just give me an answer on it, please, if you take all the permafrost in this world, how much of it is underlain by methane?

Dr. KILLEEN. If you took all the permafrost in the world, there would be so much methane that we would be an unrecognizable planet. There is huge quantities of methane in the deep permafrost.

The CHAIRMAN. Huge. Is any escaping at this point?

Dr. KILLEEN. There are measurements—I'm talking about the new surface permafrost. It's important to—there's a deep reservoir and there is new surface reservoir.

The deep reservoir is huge. The new surface reservoir is more modest, but it's clearly dynamically changing. There are—we can see in the ocean bubbles of methane coming out of methane hydrate formations in the Arctic Ocean, for example. We can see the decomposition of new surface permafrost in places like Alaska where, you know, buildings can slip because of the—so there's evidence that's some of the new surface permafrost is degrading and there are bore hole observations, as well, that show a change in the temperature distribution of the new surface permafrost in Alaska that have now systematically been done for 10–15 years and that show that the thermal balance is changing in that permafrost.

But this is a joker in the pack of our understanding of climate change because the IPCC models didn't have methane in there. The next round of models will have methane in them with some assumptions about sources in flux, et cetera, and—

The CHAIRMAN. Thank you.

Dr. KILLEEN. Thank you.

The CHAIRMAN. Mr. Alix, I was talking with the Chairman of Cisco about you and your project and he said that when he plants a tree, what he likes to do is put out about six seeds, assuming that through the process of development, one will work and the others won't.

Now, I go right back to why aren't more people latching on to what you're doing. I mean, this is a closed community. Everybody knows everything about what everybody else is doing. But the variety of solutions is just staggering in their effectiveness. You're talk-

ing 5 percent. That's right dead center on nuclear, which is considered clean, and I don't understand.

I've already asked you the question, but I want you to talk more about it. Why aren't people doing more of what you're doing or are there other iterations of what you're doing that people could be doing? Are you restricted or are others restricted because they're not working in the territory that you're working in?

Mr. ALIX. Well, I think there is an overall constraint which I mentioned earlier which is purely financial, which is it's a massive investment in capital and operating costs. As Mr. Warner mentioned, it's a 15 to 25 percent reduction in electrical output. So this is a bill for an average plant of \$20 to \$50 million a year per power plant.

The CHAIRMAN. We're talking huge companies, Mr. Alix, huge companies.

Mr. ALIX. Well, I think you'd have to ask those CEOs. My belief is they will not—there's only one CEO I know in this United States that's prepared with his shareholders and owners to spend money in advance of government incentives and a requirement and that's Ron Harper in Basin Electric and I think they're a shining example and the reason they're doing it is because they get 96 percent of their electricity from coal and their average price to their consumers is around five cents a kilowatt hour and they're worried under climate legislation that goes away. So he's stepping out. He's spending his members' money, about \$250–300 million, to prove this technology.

I have not seen one other CEO in the United States who's willing to make that investment without government backing.

The CHAIRMAN. All right. So then that's their attitude. So you say fine, then we'll tax carbon.

Mr. ALIX. I think certainly if you put a limit on CO₂ and you put a price on it, that's the beginning of a lot of action and I would support such actions.

The CHAIRMAN. So you think then the incentives become a little less necessary and the action becomes a little more active?

Mr. ALIX. Yes. I think so.

The CHAIRMAN. OK. I like that. Thank you all extremely much. You've been a terrific panel. I have to say one official thing here: we're going to keep the th record open for Committee members till March 20 of this year, Friday, for any additional questions or statements. I would like to thank each one of you.

This is such a huge subject and what's fascinating, and unfortunate in some ways, is that we have at least four committees who feel that they can do it and the question is, how we are going to meld this together. I think the answer is what's happening in the world, even with gaps in knowledge, is going to drive us to do it and with that, this hearing is adjourned.

[Whereupon, at 12:15 p.m., the hearing was adjourned.]

A P P E N D I X

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. KAY BAILEY HUTCHISON TO
DR. TIM KILLEEN

Question 1. The National Research Council in 2003 recommended the establishment of a coordinated Federal program of weather modification research designed to reduce scientific uncertainties. The program should consist of a sustained research effort that uses a balanced approach of modeling, laboratory studies, and field measurements. Instead of focusing on near-term operational applications of weather modification, the NRC Stated the program should address fundamental research questions. Do you agree with the NRC's recommendation? Do you believe the Federal Government has made any progress on this?

Answer. The NRC report recommended fundamental studies in areas of cloud and precipitation processes, and cloud dynamics. The NSF agrees that these are important areas of research and efforts are supported on these topics including field research, laboratory studies, theoretical and numerical modeling studies. In NSF's view focusing on the fundamental properties of precipitation production and cloud dynamics is the correct approach. Scientists have developed credible modification hypotheses for some, although not all, weather systems. Before we can fully test these hypotheses, we need to better understand the potential evolution paths that natural systems could follow to be able to identify when changes to the natural system have been effected.

It should be noted that field research that directly involves cloud seeding of any sort engenders many legal and social issues. Therefore, while much of NSF supported research directly contributes to the knowledge based needed to advance the science of weather modification, actual field research involving seeding agents is not currently supported by NSF. NSF, however, does consider proposals that involve laboratory experiments or numerical simulations of seeding.

The Federal Agencies have a long history of cooperation across the broad spectrum of climate and weather research and there has been progress in understanding precipitation processes, precipitation systems and severe weather. Recent examples of multi agency programs include the North American Monsoon Experiment (<http://www.eol.ucar.edu/projects/name/>), The International Water Vapor Project (http://www.eol.ucar.edu/dir_off/projects/2002/IHOP.html), and the Hurricane Rainband and Intensity Experiment (<http://orca.rsmas.miami.edu/rainex/>).

Question 2. You identified several inadequacies in your written testimony concerning the U.S. science program's modeling and observing capabilities. Does the Federal Government have a firm plan to address these inadequacies? Would the funding provided in the economic stimulus legislation be used to address these concerns?

Answer. We will address the question about modeling first. The straightforward answer is that the Federal agencies, including several interagency groups dealing with climate models of different types, have recognized the importance of improving current modeling capabilities. Some problems stem from constrained computational resources; some from inadequate understanding of fundamental processes and/or the capability to couple the relevant components of the earth system into a single model. Global climate change models are one component, albeit a very substantial one, of a knowledge system of the global integrated Earth system that includes sustained high accuracy, well-calibrated global observations with high-spatial- and high-temporal-resolution and process experiments.

There are many excellent global climate change models in the world, including three from the United States. The Community Climate System Model (CCSM), a cooperative effort between NSF and DOE is one. The others were developed at the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) and the NASA Goddard Institute for Space Studies (GISS). All three global climate change models were incorporated in the IPCC Climate Change 2007 Assessment Report. The NSF/DOE model, CCSM, is a "community model", developed collaboratively by the scientific

community and openly available as a research and development tool while the GISS and GFDL models are internally developed and available upon request.

All global climate models have shown recent tremendous progress in their ability to reliably and accurately simulate large-scale features of Earth's climate system in its rich complexity. Two examples are the accurate representation of El Niño cycles and the incorporation of the global carbon cycle.

Current limitations on global climate models are spatial resolution, that is, the smallest scale phenomenon they can represent, and complexity, where processes are left out for lack of knowledge or for computational expediency. Global climate models are striving to achieve the same level of success at geographical scales equivalent to the size of Illinois as they do for large-scale phenomena like El Niño. An example of a resolution constraint is the fact that global models cannot presently resolve hurricanes in more than a schematic way. As for complexity, current models drastically simplify the behavior of many critical phenomena—ice shelf dynamics, land-surface interactions, role of mega-cities, ecosystem dynamics and evolution, social and economics processes.

Addressing these issues requires a committed and coordinated effort across the agencies to: (1) develop a cadre of computational geoscientists, that is, people trained in computationally intense modeling as well as the sciences relevant to climate, (2) engage a broader community of interdisciplinary scientists who would use and critically evaluate regional climate model results, and (3) prioritize investments to ensure adequate infrastructure, including hardware and software system frameworks, software engineers, and the computational resources necessary to run comprehensive models at the resolutions that are relevant to society and to allow for multiple (ensemble) model runs in order to assess the uncertainty in model results.

The importance of having an observational system capable of monitoring climate change as well as providing the detailed climate information required to test the ability of models to capture critical climate processes cannot be understated. The intergovernmental GEO activities serve as a worldwide framework to define the kind of international system of observing systems that are required. The complexity of the global integrated Earth system is vast and requires international coordination. NASA and NSF play somewhat unique roles relative to many operational agencies in that NASA and NSF are not responsible for climate monitoring per se; rather, NASA and NSF observing systems complement and supplement the operational observing systems. They are designed to unearth new insights into key physical and/or biological processes and can serve as test beds for state-of-the-art sensors or sensor network configurations. Further, all of the Federal agencies recognize the importance of ensuring access to data and the tools for exploiting such data. Accelerating successful research-to-operations transitions of new measurement capabilities will help to improve understanding of global and regional climate change and to provide critically important information for adaptation to climate change.

NSF cannot speak for other agencies regarding funding they received under the American Recovery and Reinvestment Act. NSF's Recovery funds will allow us to support a number of important climate modeling and observational activities this year. Given the high priority that NSF accords such modeling and observational activities, we are committed to ensuring sustained support of these and other new capabilities into the future.

Question 3. You mentioned in your written testimony that, "The relationship between the Earth's ability to function as a set of interconnected ecosystems and the biodiversity within and among those interacting systems is an area of incomplete knowledge and critical importance." Given that, do you feel we are in a position to begin to finalize adaptation plans in response to the impacts of climate change?

Answer. Adaptation planning requires that managers and policy-makers account for the potential and likely outcomes of climate change. In the adaptive management framework, implementation cannot be considered "final." Decisions will need to be made based upon best available data and with knowledge of uncertainty about future climate change. Adaptation plans will need to be periodically evaluated and adjusted in light of new scientific findings and changing conditions. NSF sees opportunities to begin developing smart adaptation strategies through efforts that will combine natural science and social science. The process of developing and evaluating adaptation (and mitigation) strategies must be evolutionary, and strategies modified as new insights are gained. Ecosystem services and biodiversity are two areas where great scientific questions remain.

Given the significant uncertainties in how the natural, biological systems interact with the physical system, one major set of questions concerns how the living world adapts to and transforms Earth's climate. Current models of biotic change in response to climate change indicate that a large fraction of Earth's biota will need to genetically adapt, migrate, or suffer extinction. Estimates of the fraction of species

so affected vary. For example, Thomas *et al.* (*Nature*, 2004) used several different climate change scenarios to estimate a range of 15–37 percent of species committed to extinction. One recent study suggested that 50 percent or more of lowland tropical species could decline in abundance or go extinct due to climate change (Colwell *et al.*, *Science*, 2008). We know enough to expect large changes but we do not yet know enough to provide managers with specific guidance about alternative management scenarios.

At the same time, a large fraction of Earth's biodiversity is still undescribed. Perhaps 10 percent of species on Earth are named (May and Beverton, *Philosophical Transactions: Biological Sciences*, 1990). Classical approaches to biodiversity discovery are too slow to make rapid progress given the impending climate-related biotic responses. Major developments in genomic technology put within reach the possibility of determining the unknown dimensions of biodiversity within a decade.

Next generation climate models necessary to evaluate critical adaptation strategies will need better information about biological mechanisms involved in carbon, water and nutrient cycles and need to more tightly integrate across biophysical and social science disciplines. We can anticipate these next generation models will be important tools to policymakers just as current generation models have played such a large role in the IPCC.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARIA CANTWELL TO
DR. TIM KILLEEN

Question 1. NSF is considering as part of its Major Research Equipment and Facilities Construction (MREFC) an ocean observing system part of which is a regional cabled observatory with immense power and bandwidth. This is a unique capability with which to observe biological, fishery changes as well as water movements. As climate change shows up in the fisheries altering patterns of fish migration, how does NSF intend to ensure that the Ocean Observing Initiative is making good measurements of migrating species? What are their plans to ensure the network is of significant scale to monitor these changes on the west coast in conjunction with Canada which has already installed a smaller cabled network?

Answer. The mission of fisheries resource management belongs to NOAA, but many of the data and research results supported by NSF are useful to NOAA scientists in carrying out that mission. In the case of NSF's planned Ocean Observatories Initiative (OOI), sensors are included that measure the state of, and changes in, the ocean's general conditions and health (for example, temperature, pH, light penetration, dissolved oxygen content, turbidity, nutrient levels) as well as sensors that examine the base of the food web (for example, chlorophyll-derived productivity estimates of phytoplankton). These measurements provide the foundation for understanding impacts on migrating fisheries species. For NSF, using data from the OOI and its Canadian counterpart to understand the larval, juvenile and adult lifecycles of fishery species, and other marine animals is a high priority for scientists posing fundamental research questions. This information will inform our knowledge of the dynamics of fish populations and the behavior (*e.g.*, migration) of target species in the NE Pacific and the Mid-Atlantic regions, as researchers propose to use the infrastructure of OOI for deploying advanced technology to observe population and behavioral studies of targeted species.

Question 2. How is NSF working with NOAA to ensure that the regional cabled observatory and the coastal moorings off the Washington and Oregon coast can provide information that is useful for storm forecasting, and how is NSF working with USGS to ensure that the regional cabled observatory off Washington and Oregon are providing seismic information useful for earthquake, tsunami and hazard modeling?

Answer. NOAA chairs (and NSF serves as Vice-Chair) an Interagency Working Group on Ocean Observations, which meets monthly to ensure informed planning of ocean observing assets across the agencies. More specifically, program staff from NSF and the IOOS Program Office at NOAA are working together to develop data management systems for the two systems that converge and will provide universal, free, and streamlined data access to all observing data (including surface waves, mean currents and turbulent velocities, water column pressure). Within the Geosciences Directorate, the Divisions of Earth Science and Ocean Sciences are working together to combine resources from EarthScope, OOI and core programs for studies of tectonic and seismic processes off the Pacific Northwest. Long-standing partnerships between the Division of Earth Sciences and the USGS on research and monitoring of global seismic activity will enhance this research.

Question 3. Ocean acidification is a major concern to me, and I've worked with Senator Lautenberg to pass legislation to make sure our government conducts research on this important topic. I'm concerned, though, how often major climate reports, assessments and programs ignore or omit the topic of ocean acidification. If we create a Federal Climate Service, should that service also be responsible for ocean acidification? Shouldn't ocean acidification be given more attention in the climate conversation and forums like the International Panel on Climate Change and the major climate change study being conducted by the National Research Council?

Answer. The research community is concerned that increasing ocean acidification will have a significant impact on ocean ecosystems and food webs, natural ocean carbon sequestration and broader ocean chemistry; based on science done within the last several years. In fact, beginning in 2007, NSF established dedicated new budget lines for ocean acidification research.

A number of activities are ensuring that ocean acidification will be appropriately recognized in other arenas. The Ocean Studies Board has commenced a study on the "Development of an Integrated Science Strategy for Ocean Acidification Monitoring, Research and Impacts Assessment," supported by NOAA, along with NSF and other agencies. The Omnibus Public Land Management Act of 2009, signed by President Obama on March 30, includes legislation on ocean acidification (FORAM). The legislation includes authorization levels for research at NSF and other agencies, and also for a coordinated inter-agency approach to coordinating research across the agencies, integrating research with adaptation and mitigation strategies, and providing information for policymakers.

Question 4. Particularly in the field of renewable energy, new companies are emerging that want to provide climate data services for the private sector. For example, a company in my home state of Washington called 3TIER has set out to provide climate and weather data for wind, solar, and hydropower energy providers. In your opinion, where should the line be drawn between the climate services the Federal Government should provide and the services the private sector should be providing? As we move forward with more sophisticated government climate services in the future, what steps should we take to make sure we are not unnecessarily expanding into areas that are most appropriate for the private sector?

Answer. There is a long standing and successful public—private partnership for weather and climate services. I expect that to continue and serve as a model for the future roles of the private and public sectors. The challenge lies in the new emphasis on climate rather than weather products and the fact that climate can no longer be treated as stationary. Robust predictions will depend on the results of intense modeling efforts and operational observations, the effort and expense of which will most likely continue to be borne by government agencies.

Within the Nation there is significant demand for information about climate, but a lack of appreciation about the uncertainties in today's climate projections that will serve as the basis for developing region-specific products. The public—private enterprise will be in "new territory" in the next decade as we learn to deal with a changing climate, but the basic public-private relationship is unlikely to change much. The government recognizes that it can provide information that is more immediately useful to users (including the private sector) as well as new decision support tools, but it will be the private sector that can best meet specific needs for the majority of end-users.

Traditionally, the private sector has played an important role in providing both weather and climate services to the Nation. The private sector is well positioned to provide value-added climate products tailored to meet the specific needs of a range of customers. The need for "tailored" information comes about because the many different users of climate information have distinct and varying needs depending on the sector, the activities involved, the size of the operation, the time-frame for which information is relevant to the enterprise, etc. The private sector can serve as the "translator" of climate information—assessing users' needs and developing value-added products that meet those needs—and updating those products as new understanding about the climate system emerges.

The public sector has traditionally maintained the observing systems and related data bases as well as supported the development of the sophisticated, complex, and computationally demanding, weather and climate models that serve as the basis for weather and climate information. For the most part, these are operational and certainly resource-intensive activities. Further, the government has provided the support for long-term research and observational system investments that will ultimately lead to improved understanding of climate and provide for the basis for new and better products, products that are still many years from being commercially viable.

Question 5. While climate mitigation is essential, I think there needs to be a much more serious discussion on our Nation's plan to adapt to climate change. In your opinion, what are some of the most common and likely mistakes our communities and government will make in the coming years if we don't have the climate information and adaptation measures needed to avoid poor long-term decisionmaking? Aren't climate adaptation measures necessary to avoid making poor decisions on long-term infrastructure—poor decisions that can be both costly and dangerous? Without climate adaptation, don't we risk building a legacy of poor infrastructure decisions?

Answer. The best way to answer your question might be to point out that climate adaptation will be a process rather than a one-time fix. The actual state of the climate will be a moving target that will be the result of the policy choices that are made regarding mitigation and the resulting levels of greenhouse gas concentrations in the atmosphere over the coming decades. In that sense, adaptation choices are not truly independent of our mitigation choices. Depending on greenhouse gas concentrations, the temperature and precipitation patterns likely will change gradually with time, with occasional periods of more rapid change being possible. At this point, we are fairly confident about the broad outlines of how climate will change, but we don't know the details. There much we need to learn. Various sectors will need to respond at quite different timescales, so for example, planning for water resources infrastructure generally is longer than for some decisions that will be made in the agricultural and forestry sectors.

The most likely mistake that could be made by both communities and the government would be to adopt a "one size fits all" approach to climate adaptation. As noted above, there are a wide range of needs. Ideally, adaptation choices will have been made based on a regional, not just local, basis. Further, the strategies that are adopted must consider that the knowledge of climate is imperfect and so a range of climate scenarios should be considered. An equally likely and costly mistake might be to assume that that there will be no unintended consequences from our adaptation actions. Given these considerations, it is imperative that we continue to develop both a better understanding of climate processes and a set of tools that can comprehensively assess the likelihood of the outcomes for our adaptation (and mitigation) choices. Developing the kind of high resolution, complex climate prediction models and decision support tools that would allow us to assess the choices adequately is within the realm of possibility, but not yet in our grasp. That capability will require investment in further research.

With regard to major infrastructure planning, there are many factors that must be taken into account. Human success is in part due to our ability to adapt to changing circumstances, and as we plan for long-term infrastructure investments, making sure our infrastructure is designed not only for today but the future is critical. Infrastructure choices are, in fact, part of adaptation, but the decisions should always be informed by the best science possible. As noted in my testimony, we are at a point where that science must include both the natural and social sciences. In addition, NSF supports research in the science of decision-making under conditions of uncertainty. Decision-makers normally must make choices with either imperfect or inadequate knowledge. This scientific research area seeks to identify ways to reduce risk in decisionmaking and improve potential outcomes. We see this as a key decision support tool. Certainly anything that can be done to better inform infrastructure decisions—both having better estimates of the likely evolution of the climate (and other factors) as well as procedures for reducing risks—will reduce the possibility of making poor choices.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARIA CANTWELL TO
KATHARINE JACOBS

Question 1. Particularly in the field of renewable energy, new companies are emerging that want to provide climate data services for the private sector. For example, a company in my home state of Washington called 3TIER has set out to provide climate and weather data for wind, solar, and hydro power energy providers. In your opinion, where should the line be drawn between the climate services the Federal Government should provide and the services that the private sector should be providing? As we move forward with more sophisticated government climate services in the future, what steps should we take to make sure that we are not unnecessarily expanding into areas that are most appropriate for the private sector?

Answer. I am familiar with 3TIER, two of my colleagues are in that group, and they are very talented. In my opinion, the Federal Government should provide climate information for a broad range of audiences. If particular industries want infor-

mation that is more tailored to their location or their specific decision processes, that is an appropriate place for the private sector to step in. There are many reasons why the government should engage in providing climate services. One is to provide equitable access to information. If all of these services were only available if paid for, then those who may need it most, the economically disadvantaged, may have the least access to it. A second reason is that provision of climate information is directly related to health and welfare. If this information is only available through the private sector, then the profit motive controls information that could be of critical importance to saving lives and property. In addition, much of the climate observing system was paid for with taxpayer dollars. They have a right to some sort of return from that investment.

I believe that we can use considerations such as equity, national security, health and welfare, and return on investment as guidance in determining whether the Federal Government should engage in providing services.

Question 2. While climate mitigation is essential, I think there needs to be a much more serious discussion on our Nation's plan to adapt to climate change. In your opinion, what are some of the most common and likely mistakes our communities and government will make in the coming years if we don't have the climate information and adaptation measures needed to avoid poor long-term decisionmaking? Aren't climate adaptation measures necessary to avoid making poor decisions on long-term infrastructure—poor decisions that can be both costly and dangerous? Without climate adaptation, don't we risk building a legacy of poor infrastructure decisions?

Answer. There is much more information needed for good adaptation decisions, particularly in designing infrastructure that will be robust in the context of more extreme events, both flood and drought. In the short term, it is the capacity to deal with extreme events that is lacking, especially in light of the very poor condition of all infrastructure in this country—water and wastewater infrastructure, transportation, etc. I would anticipate the greatest danger in the short term comes from poor management of floodplains and from coastal storm surges. Climate adaptation does require that we re-examine the engineering standards that are used in designing infrastructure. Especially in light of the stimulus package, it is important that these standards be revised quickly to avoid maladaptive investments. We do risk building a legacy of poor infrastructure that may last 50 years or more if we do not take changing climate conditions into account.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARK WARNER TO
FRANK ALIX

Question 1. Carbon sequestration holds promise and we are gaining certainty, through demonstration projects like yours, about how to control the risks involved with the process. Can you briefly tell us the genesis of your ECO₂ capture process and how it will lessen risks when transferring from smaller projects to a commercial scale capture and sequestration plant?

Answer. Our ECO₂ capture process was initially developed in conjunction with U.S. DOE's National Energy Technology Laboratory (NETL), which had performed some of the pioneering research on CO₂ capture with ammonia. We jointly developed ECO₂ with NETL under a cooperative research and development agreement (CRADA).

In order to reduce risks associated with commercial-scale CCS projects, we designed our ECO₂ pilot test facility using the same type of equipment we plan to use in larger, commercial-scale systems. This eliminates most of the risk associated with building commercial scale systems, as all of the equipment needed for these systems has been demonstrated on our pilot unit and is already commercially proven at scale (the innovation in ECO₂ is in its process chemistry).

Question 2. Many power companies use coal to generate electricity because it is less expensive than natural gas. How will the additional cost of carbon sequestration impact the economics of coal as a competitor to natural gas?

Answer. CCS would add significant costs to coal-fired electricity generation, on the order of 3 to 4 cents per kWh. This would make coal-fired generation less competitive with gas. However, assuming the price of CO₂ emission allowances rises to \$30–40 per ton, there would also be a cost impact on gas-fired generation as it emits about half as much CO₂ as a coal plant (therefore the equivalent cost impact on gas-fired generation would be 1.5 to 2 cents per kWh). In this scenario, based on projected future prices for coal and natural gas, coal would remain the low cost electricity source when compared to gas.

Question 2a. What types of coal have been used in your carbon sequestration process? How do various coal types impact the economics of your process?

Answer. Our carbon capture process has been tested on a blend of bituminous and subbituminous coals. However, we do not expect the type of coal to have any impact on our CO₂ capture performance. ECO₂ should perform equally as well for all coal types. The two factors that will affect CO₂ capture costs are plant efficiency (higher efficiency yields less CO₂ per kWh, means reduced costs) and new versus retrofit (retrofit costs will be higher than new plants).

Question 3. How clean and energy efficient is your ECO₂ process? Would you describe how your process affects the amount and sanitation of the water used, and how much energy is saved or spent overall using your technology?

Answer. Our CO₂ capture process does not consume water except as needed for cooling, and processes exist which can provide the necessary cooling without water use (*i.e.*, air coolers). If cooling water is used, its quality should remain unaffected as cooling water would be contained in a closed system and not come in contact with process gas or liquids.

Our ECO₂ process is expected to require 15–20 percent of the net power output from a new, supercritical coal-fired power plant to capture and compress 90 percent of its CO₂. For retrofit of an existing coal-fired power plant, the energy cost is expected to be 20–25 percent.

