Introduction and Personal Perspective. If I may indulge in a personal note at the outset. It is a pleasure to appear again in front of both Senators McCain and Lieberman on climate change issues, having had that honor on several occasions since the mid 1980s with Senator McCain, and the mid 1990s with Senator Lieberman. As these hearing today are about the “case for action” on climate change, based on sound science assessment, I will try to emphasize aspects of the science of climate change less exhaustively covered by other witnesses, such as Dr. Tom Wigley of the National Center for Atmospheric Research, whose testimony on climate change science I fully associate myself with. Instead, I will focus more on as aspects of science so well stated by Senator Lieberman when I testified to the Senate Environment and Publics Works Committee, chaired by the late Senator Chaffee, in July 1997. At that time Senator Lieberman said:

“Changes in climate have major implications for human health, water resources, food supplies, infectious diseases, forests, fisheries, wildlife populations, urban infrastructure, and flood plains and coastal developments in the United States. Although uncertainties remain about where, when and how much climate might change as a result of human activities, the changes—when they happen—may have severe impacts on many sectors of the U.S. economy and on the environment. These are serious risks that we must start considering” (p. 15)

This statement is equally valid today, and can be further supported by substantially more scientific studies pointing out potentially serious climate impacts. I will briefly review some of these, and put them in the context of climate change cost/benefit analyses. But first, a brief statement about the climate change science itself.

While testifying to this Committee on May 8, 1989—with Senator McCain then being a member of the Committee—I recall a discussion about the problem of uncertainties and how long we should wait before action. Moreover, some debaters had asserted that there wasn’t enough direct evidence of human-induced climate change for strong policy actions. In response to senators from this committee on that point, I agreed that “most of our confidence that the future will change is about the heat trapping properties of gases, not based so much on the performance of the planet this century.

If we insist on waiting for the planet to catch up to what we expect it to do, it is another 10 to 20 years to prove that beyond doubt” (p.150)

Well, it is now 14 years since I said that. I believe the work of the Intergovernmental Panel on Climate Change (IPCC), the U.S. National Academy of Sciences (NAS) and others has amply demonstrated that, indeed, nature has “caught up” with our expectations of warming, and in fact added a few surprises such as rapid changes in
polar regions and devastating heat-wave induced deaths, even in modern, highly developed countries, like happened in France this past summer with ten thousand or more victims of that rare heat.

The surface warming trends are solidly grounded in observational science and consistent with human-induced pressures. It is scientifically well established that the Earth’s surface air temperature has warmed significantly, by about 0.6 °C since 1860, and that an upward trend can be clearly discerned by plotting historical temperatures. Such a graph would show a rapid rise in temperature at the end of the twentieth century. This is supported by the fact that all but three of the ten warmest years on record occurred during the 1990s. But what has been learned only in the past half-decade is that this unusual warmth is not just for the past 140 years, but the past 2000, as Figure 1 displays.

Figure 1. Two millennium reconstruction of global temperature changes in degrees Celsius (blue line), with 95% confidence band shown in yellow and the instrumental record in red. Notice that the last several decades of the 20th century exceed the range of temperatures over the past 2000 years. Source: Mann and Jones, 2003

The probability that the radical upward swing in temperature at the tail end of the 20th century being just a natural quirk of nature—as some “contrarians” and their political supporters contend—is an exceedingly low probability. If, as some assert, “the sun did it”, then what was the sun doing over the previous 2 millennia? It is rather perverse to expect such a radical behavior from the sun just now—when we have clear evidence of human-induced pressures coincident with the warming. While it cannot be ruled out as a possibility (at some low probability) that natural factors are responsible for the unusual warmth of the Earth’s surface at the end of the 20th century, we have much more likely explanations in the mix of natural and human-induced (anthropogenic) factors. More disquieting are projections for the 21st century if we continue business as usual for greenhouse gas emissions. It is for such reasons that I just expressed my personal satisfaction for having over the past two decades had the opportunity to testify to the Senators currently leading this effort to establish a meaningful climate change policy for the United States that actually will result in emissions reductions. In my personal opinion it is essential that we get on with the job of providing mandatory incentives to encourage the
amazing industrial and intellectual capacity of our country to fashion cost-effective solutions. I thank the Senators for having stayed with this issue over the long term.

In addition to observations of nature cooperating with theory by evidencing record warmth in the past few decades, it is well established that human activities have caused increases in radiative forcing, with radiative forcing defined as a change in the balance between radiation coming into and going out of the surface-atmosphere system. In the past few centuries, atmospheric carbon dioxide has increased by more than 30 percent, and virtually all climatologists agree that the cause is human activities, in particular, the burning of fossil fuels.

Despite the many well established aspects of the science of climate change (e.g., anthropogenic forcing of global warming), other aspects (e.g., detailed regional changes) are still being vigorously debated. The climate change debate is characterized by deep uncertainty, which results from factors such as lack of information, disagreement about what is known or even knowable, linguistic imprecision, statistical variation, measurement error, approximation, subjective judgment, and disagreement about structural models, among others (see Moss and Schneider, 2000). These problems are compounded by the global scale of climate change, which produces varying impacts at local scales, long time lags between forcing and its corresponding responses, very long-term climate variability that exceeds the length of most instrumental records, and the impossibility of before-the-fact experimental controls or empirical observations (i.e., there is no experimental or empirical observation set for the climate of, say, 2050 AD, meaning all our future inferences cannot be wholly “objective,” data-based assessments — at least not until 2050 rolls around). Moreover, climate change is not just a scientific topic but also a matter of public and political debate, and degrees of uncertainty may be played up or down (and further confused, whatever the case) by stakeholders in that debate.

Can We Define What is “Dangerous" Climate change? Article 2 of the UN Framework Convention on Climate Change (UNFCCC) states that: “The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system”. The Framework Convention on Climate Change further suggests that “Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.”

Thus, the term “dangerous anthropogenic interference” may be defined or characterized in terms of the consequences (or impacts) of climate change outcomes, which can be related to the levels and rates of change of climate parameters. These parameters will, in turn, be determined by the evolution of emissions and consequent atmospheric greenhouse gas concentrations. Evaluating the consequences of climate change outcomes to determine those that may be considered “dangerous” is a complex undertaking, involving substantial uncertainties as well as value judgments. In this context, the role of scientists is to assess the literature with a view to providing information that is policy-relevant, without being policy prescriptive.

Climate Sensitivity and Climate Scenarios to 2100 and Beyond. By how much will humans and natural changes in the Earth each contribute to future disturbance? The IPCC has attempted to tackle this controversial issue in its Special Report on Emission Scenarios (SRES), which contains a range of possible future climate scenarios based on different assumptions regarding economic growth, technological developments, and population growth, arguably the three most critical determinants of future climate change. These have been used to project the increases in CO₂ concentrations and temperature out to 2100. These and other climate change projections depend on detailed modeling. The most consistent way scientists codify knowledge is by constructing models made up of the many subcomponents of the climate system that reflect our best understanding of each subsystem. The system model as a whole cannot be directly verified before the fact —
that is, before the future arrives — but it can be tested against historical situations that resemble what we believe will occur in the future.

While modeling has become both more complex and more accurate as computing abilities have advanced and more is understood about the climate problem, scientists still have to deal with an enormous amount of uncertainty, as mentioned above. In modeling, a major uncertainty is climate sensitivity, the amount by which the global mean surface air temperature will increase for a doubling of CO₂ concentrations. Many scientists have done extensive modeling and observational research on this subject over the past 20 years, and most have agreed that climate sensitivity probably falls somewhere within the IPCC’s range of 1.5-4.5 °C. However, that old consensus is changing, as several recent studies (e.g., Andronova and Schlesinger, 2001, Forrest et al 2001) have estimated that climate sensitivity could be an alarming 6 °C or higher. (Remember that a 5-7 °C drop in temperature is what separates Earth’s present climate from an ice age.)

The most comprehensive models of atmospheric conditions are three-dimensional, time-dependent simulators known as general circulation models (GCMs). Because of the complexity and computational costs of GCMs, simpler models are often constructed to explore the sensitivity of outcomes to plausible alternative assumptions for the structure of the climate system and the possible scenarios of human activities which cause climatic forcing (e.g., Wigley, testimony to this session). Together, the fan of possible climate scenarios and the probability distributions of possible climate sensitivities, determine what policy makers often want to know—by how much will it warm in, say, 2100 (or any other time) depending on what policies we choose to change emissions scenarios (e.g., Schneider, 2002). IPCC has addressed this issue in many of its assessments. The combined effects of uncertainties in emissions and uncertainties in climate sensitivity—what determines the range of potential future temperature changes at some future date—are also known as a “joint probability” estimation (i.e., sensitivity and emissions varied jointly).

Consider another simple way to approach this question of the joint probability of temperature rise to 2100 and crossing some “dangerous” warming threshold, to use the language of the UNFCCC—which, by the way, was signed by President Bush in 1992 and ratified by the Senate). Instead of using two probability distributions, an analyst could pick a high, medium, and low range for each factor and plot the results. For example, a glance at Andronova and Schlesinger’s calculations shows that the 10 percentile value for climate sensitivity is 1.1 °C for a doubling of CO₂ (i.e., 4 W/m² of radiative forcing). 1.1 °C is, of course, below the IPCC's lower limit climate sensitivity value of 1.5 °C. However, this merely means that there is a 10 percent chance climate sensitivity will be 1.1 °C or less — that is, a 90% chance climate sensitivity will be 1.1 °C or higher. The 50th percentile result — that is, the value at which climate sensitivity is as likely to be above as below — is 2.0 °C. The 90th percentile value for climate sensitivity from Andronova and Schlesinger (2001) is 6.8 °C, meaning there is a 90% chance climate sensitivity is 6.8 °C or less, but there is still a very uncomfortable 10% chance it is even higher than 6.8 °C — a value well above the 4.5 °C figure that marks the top of the IPCC's range. Using these three values to represent a high, medium, and low climate sensitivity can produce three alternate projections of temperature over time, once an emissions scenario is decided on. In Root, Root and Schneider (in preparation), the three climate sensitivities just explained were combined with two SRES storylines: A1FI, the very high emissions, fossil fuel-intensive scenario; and A1T, the high technological innovation scenario, in which development and deployment of advanced technologies dramatically reduces the long term emissions. This comparison pair almost brackets the high and low ends of the 6 SRES representative scenarios’ range of cumulative emissions to 2100, and since both are for the “A1 world,” the only major difference between them is the technology component — a “policy lever” that could be activated through the implementation of policies to encourage decarbonization—like the bill before this committee. Therefore, asking how different the evolution of projected climate is to 2100 for the two different scenarios is a very instructive exercise and can help in exploring in a partial way the different likelihood of crossing “dangerous” warming thresholds. To be conservative, I’ll use a 3.5 °C threshold for “dangerous” climate change, though I’ll show shortly it could be lower or higher.
Figure 3 — Three climate sensitivities and two scenarios
As noted in Figure 3 above, the three climate sensitivities — 10th, 50th and 90th percentiles — designated by Andronova and Schlesinger (2001) are combined with the radiative forcings for the A1FI and A1T scenarios. The dashed horizontal lines in both graphs represent the 3.5°C threshold, and the blue shaded area marks the extent to which the two temperature change scenarios exceed that 3.5°C threshold. These produce similar projections of warming for the first several decades of the 21st century, but diverge considerably — especially the high-sensitivity 90th percentile case — after mid-century. The 50th and 90th percentile A1FI cases both exceed a threshold of 3.5°C warming before 2100, and the area shaded in blue is much more dramatic in the fossil intensive scenario than the technological innovation scenario. In fact, at 2100, when the A1T curves are stabilizing, the A1FI temperatures are still upwardly sloped — implying greater warming in the 22nd century. Thus, in order to fully assess “dangerous” climate change potential, simulations that cover well over 100 years are necessary since it is widely considered that warming above a few degrees Celsius is likely to be much more harmful than for changes below a few degrees (see Figure 5 below).

How Long is a “Long View”? The most striking feature of both scenarios in Fig 3 is the top (red) line, which rises very steeply above the other two lines below. That is because of the peculiar shape of the probability density function for climate sensitivity in Andronova and Schlesinger. [For those concerned with the technical details, that is because it has a long tail to the right due to the possibility that aerosols have been holding back not-yet-realized warming.] Also striking is that both the 10th and 50th percentile results for both the A1FI and A1T scenarios don’t differ much in 2050, but then diverge considerably by 2100. This has led some to declare (erroneously, in my view) that there is very little difference in climate change across scenarios or even among different climate models with different sensitivities. This is clearly wrong, for although both A1FI and A1T have emissions, and thus CO₂ concentration projections, that are not very different for the first several decades of the 21st century, they diverge after 2050, as does the temperature response. For the 90th percentile results, both the A1FI and the A1T temperature projections exceed the “dangerous” threshold of 3.5°C at roughly the same time (around 2040), but the A1FI warming not only goes on to outstrip the A1T warming, but is still steeply sloped at 2100, implying warming beyond 13°C in the 22nd century, which would undoubtedly leave a dramatic legacy of environmental change for distant posterity, and great ecological stress for nature.

This simple pair of figures shows via a small number of curves (6 in all) the probability of temperature changes over time for three climate sensitivity probabilities, but does not give probabilities for emissions scenarios themselves; only two are used to “bracket uncertainty,” and thus no joint probability can be gleaned from this exercise. This is the next step that needs to be taken by the research community. An MIT integrated assessment group (Webster et al, 2003) has already attempted it using a series of different models and expert judgments to fashion a probability distribution for future climate. That approach, I predict, will be the wave of the future in such analyses, but given the heavy model-dependence of any such results, individual “answers” will remain controversial and assumption-bound for a considerable time to come.

The likelihood of threshold-crossing is thus quite sensitive to the particular selection of scenarios and climate sensitivities used. However, in these bracketing studies the probability of crossing “dangerous” thresholds of climate change is typically tens of percent—a risk society will have to weigh against the costs of climate mitigation activities. As will be discussed shortly, that is a potentially high risk indeed.

If conventional economic discounting were applied, some present-day “rationalists” might argue that the present value of damages postponed for a century or so is virtually nil. But what if our behavior were to trigger irreversible changes in sea levels, ocean currents or the extinction of species (on civilization time scales)? Is it fair to future generations for us to leave them the simultaneous legacy of more wealth and severe ecosystem damage? That is the policy dilemma thoughtful analysts of the climate policy debate have to ponder, since the next few generations’ behaviors will precondition to a considerable extent the long-term evolution of the climate and the planetary ecosystems.

**Model Validation** How can modelers be more confident in their model results? How do they know that they have taken into account all economically or ecologically or climatologically significant processes, and that they have satisfactorily “parameterized” processes whose size scales are below that of their models’ grid cells? The
answer lies in a variety of model validation techniques, most of which involve evaluating a model's ability to reproduce (for climate models, for example) known climatic conditions in response to known forcings. One form of model validation has to do with climatic response to volcanic eruptions. Major volcanic eruptions inject so much sulfuric haze and other dust into the stratosphere that they exert a global cooling influence that lasts several years and provide good tests for climate models. Such eruptions occur somewhat randomly, but there is typically one every decade or so, and they constitute natural “experiments” that can be used to test climate models. The last major volcanic eruption, of the Philippine volcano Mt. Pinatubo in 1991, was forecast by a number of climate modeling groups to cool the planet by several tenths of a degree Celsius. That is indeed what happened.

*Figure 4: Predicted and observed changes in global temperature after the 1991 eruption of Mt. Pinatubo.*
*(source: Hansen et al, 1996).*

Figure 4 shows a comparison between actual observed global temperature variations and those predicted by a climate model, for a period of five years following the Mt. Pinatubo eruption. Now, a few tenths of a degree Celsius is small enough that the observed variation just might be a natural fluctuation. However, earlier eruptions including El Chichón in 1983 and Mt. Agung in 1963 were also followed by a marked global cooling of several tenths of a degree Celsius. Studying the climatic effects from a number of volcanic eruptions shows a clear and obvious correlation between major eruptions and subsequent global cooling. Furthermore, a very simple calculation shows that the negative forcing produced by volcanic dusts of several watts per square meter is consistent with the magnitude of cooling following major volcanic eruptions. Viewed in light of these data,
the graph above suggests that climate models do a reasonably good job of reproducing the large-scale climatic effects of volcanic eruptions on a few-year time scale.

Seasonality provides another natural experiment for testing climate models. Winter weather typically averages some fifteen degrees Celsius colder than summer in the Northern Hemisphere and five degrees colder in the Southern Hemisphere. (The Southern Hemisphere variation is lower because a much larger portion of that hemisphere is water, whose high heat capacity moderates seasonal temperature variations.) Climate models do an excellent job reproducing the timing and magnitude of these seasonal temperature variations, although the absolute temperatures they predict may be off by several degrees in some regions of the world. However, the models are less good at reproducing other climatic variations, especially those involving precipitation and other aspects of the hydrological cycle. Of course, reproducing the seasonal temperature cycle alone — since these variation come full circle in only one year — does not guarantee that models will accurately describe the climate variations over decades or centuries resulting from other driving factors such as increasing anthropogenic greenhouse gas concentrations. However, the fact that models do so well with seasonal variations is an assurance that the models' climate sensitivity is unlikely to be off by a factor of 5 - 10, as some greenhouse “contrarians” assert.

Climate Impacts. Let us consider some of the effect that might occur in our century if SRES emissions do occur and typical models are used to calculate the climatic consequences of those scenarios unfolding. These changes then allow us to estimate potential impacts of climate changes, and in turn, the “climate benefits” of mitigation that avoids some of those potential damages.

Table 1 is IPCCs summary of a number of such projected effects. It has allowed, via extensive literature assessments, the integrated assessment of “five reasons for concern” if climate changes as the joint variation of SRES scenarios and climate models—see Figure 5.

Table 1 — Projected effects of global warming during the 21st Century (adapted from IPCC 2001b, table SPM-1).

<table>
<thead>
<tr>
<th>Projected Effect</th>
<th>Probability estimate</th>
<th>Examples of Projected Impacts with high confidence of occurrence (67 – 95% probability) in at least some areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher maximum temperatures, more hot days and heat waves over nearly all land areas</td>
<td>Very likely (90-99%)</td>
<td>Increased deaths and serious illness in older age groups and urban poor Increased heat stress in livestock and wildlife Shift in tourist destinations Increased risk of damage to a number of crops Increased electric cooling demand and reduced energy supply reliability</td>
</tr>
<tr>
<td>Higher minimum temperatures, fewer cold days, frost days and cold waves over nearly all land areas</td>
<td>Very likely (90-99%)</td>
<td>Decreased cold-related human morbidity and mortality Decreased risk of damage to a number of crops, and increased risk to others Extended range and activity of some pest and disease vectors Reduced heating energy demand</td>
</tr>
<tr>
<td>Event</td>
<td>Probability</td>
<td>Consequences</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------</td>
<td>-------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| More intense precipitation events                                     | Very likely (90-99%) over many areas | Increased flood, landslide, avalanche, and mudslide damage  
Increased soil erosion  
Increased flood runoff  
increasing recharge of some floodplain aquifers  
Increased pressure on government and private flood insurance systems and disaster relief |
| Increased summer drying over most mid-latitude continental interiors and associated risk of drought | Likely (67-90%) | Decreased crop yields  
Increased damage to building foundations caused by ground shrinkage  
Decreased water resource quantity and quality  
Increased risk of forest fire |
| Increase in tropical cyclone peak wind intensities, mean and peak precipitation intensities | Likely (67-90%) over some areas | Increased risks to human life, risk of infectious disease epidemics and many other risks  
Increased coastal erosion and damage to coastal buildings and infrastructure  
Increased damage to coastal ecosystems such as coral reefs and mangroves |
| Intensified droughts and floods associated with El Niño events in many different regions | Likely (67-90%) | Decreased agricultural and rangeland productivity in drought- and flood-prone regions  
Decreased hydropower potential in drought-prone regions |
| Increased Asian summer monsoon precipitation variability            | Likely (67-90%) | Increase in flood and drought magnitude and damages in temperate and tropical Asia |
| Increased intensity of mid-latitude storms                           | Uncertain (current models disagree) | Increased risks to human life and health  
Increased property and infrastructure losses  
Increased damage to coastal ecosystems |
Figure 5 — Reasons for concern about climate change impacts (source: IPCC WG 2 TAR, figure SPM-2). The left part of the figure displays the observed temperature increase up to 1990 and the range of projected increases after 1990 as estimated by IPCC, WG I (IPCC, 2001a) for scenarios from the Special Report on Emission Scenarios. The right panel displays conceptualizations of five reasons for concern regarding climate change risks evolving through 2100. White indicates neutral or small negative or positive impacts or risks, yellow indicates negative impacts for some systems, and red means negative impacts or risks that are more widespread and/or greater in magnitude. This figure shows that the most potentially dangerous impacts (the red colors on the figure) typically occur after a few degrees warming — thus, my earlier (Fig 3) use of 3.5°C as a tentative “threshold” for serious climate damages is very conservative (the European Union has suggested a “dangerous” level for warming at about 2°C). The risks of adverse impacts from climate change increase with the magnitude of climate change.

It is important that scientists continue to develop stronger models and probe the issue of climate sensitivity, as improvements in the science will lead to improvements in our understanding of the potential impacts of various levels of temperature change.

Despite uncertainties surrounding emission scenarios and climate sensitivity, the IPCC has projected that, if its latest estimate that the Earth's atmosphere will warm somewhere between 1.4 and 5.8 °C by 2100 is correct, likely effects will include: more frequent heat waves (and less frequent cold spells); more intense storms (hurricanes, tropical cyclones, etc.) and a surge in weather-related damage; increased intensity of floods and droughts; warmer surface temperatures, especially at higher latitudes; more rapid spread of disease; loss of farming productivity and/or movement of farming to other regions, most at higher latitudes; rising sea levels, which could inundate coastal areas and small island nations; and species extinction and loss of biodiversity (see table 1).
In What Units Can We Measure Climate Damage? Schneider, Kuntz-Duriseti, and Azar (2000) have argued that the best way to estimate the full extent of such damages comes from examining not just monetarily-quantifiable ("market") damage, but the "five numeraires": monetary loss (market category), loss of life, quality of life (including coercion to migrate, conflict over resources, cultural diversity, loss of cultural heritage sites, etc.), species and/or biodiversity loss, and distribution/equity. Assessing climate impacts in all these metrics should ensure a fairer, more accurate assessment of the actual costs of global warming.

This last numeraire, the issue of equity in climate change, is, and will likely continue to be, contentious. Climate change inequality will likely come in two forms. First, it will produce inequity in effects. Some countries or sectors within countries will benefit from a certain degree of warming, whereas others will be harmed by it. The developed countries, who are responsible for most of the greenhouse gases emitted into the atmosphere thus far, may not be affected as much as the developing countries for two reasons: First, there is usually higher adaptive capacity in richer, cooler countries than in poorer, warmer ones. Second, developing countries that have not yet experienced the economic fruits of the Victorian Industrial Revolution, and want their chance to emit and industrialize, fear that policies to restrict emissions will deny them their “fair share” of the atmospheric commons to use—quite literally—as a waste dump. One strategy to solve this problem is “technology leapfrogging,” the transfer or development of cleaner technologies to developing countries on a much-accelerated time schedule (relative to the developments that have emerged over a century in now-rich countries). Moreover, as there are disparities in countries’ abilities to pay for global warming-related problems, once again, the developing countries will be affected more yet have less of an ability to pay than the rich nations. While I agree it is essential to deal with climate policy at home—and thus personally applaud this bill before the committee today—we will have to join with other countries to fashion joint solutions shortly after that if we are to fashion global solutions.

Nature Is Responding Already. One of the numeraires was conservation of biodiversity. Very recent studies (e.g., Root et al 2003; Parmesan and Yohe, 2003) have shown that nature is already responding to climate trends of the past several decades. Figure 6, for example, shows by how many days each decade traits of plants and animals (such as dates of flowering of trees, migration times in the spring for birds or the range boundaries of butterflies) are already statistically significantly changed owing to observed climate trends. That warmer weather would make flowers bloom earlier is hardly surprising, but that “only “ 0.6 °C warming to date has already caused a “discernible impact” of recent temperature trends on plants and animals is surprising. Moreover, it is sobering to consider what major movements would likely take place for species if the climate changes by several degrees or more—what Figure 5 suggests are major reasons for concern.
Figure 7. Frequency of species and groups of species with a temperature-related trait changing by number of days in 10 years for data gathered primarily since 1960. The arrow indicates the mean and the “x” indicates no data were tabulated for species showing no clear trait changes. This is a highly statistically significant result demonstrating that there has been a discernible impact of recent climate trends on plants and animals such that their vital activities that are linked to temperature are occurring earlier, in concert with global warming trends (Source, Root et al, 2003)

Another clear climate impact is the highly significant retreat of mountain glaciers. This is more than just the disruption of scenic beauty as the glaciers of Glacier National Park continue to disappear, but can be damaging to societies that suffer from flooding in the current glacier melting stage, and will suffer from lack of water when their accustomed supplies dry up as the glaciers disappear. Figure 8 shows this dramatically for the “snows of Kilimanjaro”, as they are now about 80-90% gone relative to a hundred years ago.
Climate Surprises? Estimating climate damages that are expected to occur gradually and their effects is simple relative to forecasting "surprise" events and their consequences. The IPCC and others have stated that "dangerous" climate change, including surprises, are more likely to occur with more than a few degrees Celsius of additional warming. Surprises, better defined as “imaginable abrupt events”, could include deglaciation and/or the alteration of ocean currents (the most widely-used example of the latter being the collapse of the Thermohaline Circulation, or THC, system in the North Atlantic). Rather than being ignored as unlikely, surprises and other irreversibilities like plant and animal extinctions should be treated like other climate change consequences by scientists performing risk assessments, where risk is defined as probability x consequence. The probability component of the risk equation will entail subjective judgment on the part of scientists, but this is far preferable to ignoring the risk equation entirely by pretending these risks didn’t exist.

Policymakers will be better able to determine what is "dangerous" and formulate effective legislation to avoid such dangers if probabilities appear alongside scientists' projected consequences. These probabilities and consequences will vary regionally. In general, temperature rises are projected to be greatest in the subpolar regions, and to affect the polar winter more dramatically than the summer. Hotter, poorer nations (i.e., developing nations near the equator) are expected to suffer more dramatic effects from climate change than
their developed neighbors in the North. This is partly due to the lower expected adaptive capacities of future societies in developing nations when compared with their developed counterparts, which in turn depend on their resource bases, infrastructures, and technological capabilities. This implies that damages may be asymmetrically felt across the developed/developing country divide. The scenario in which climate change brings longer growing seasons to the rich northern countries and more intense droughts and floods to the poor tropical nations is clearly a situation ripe for increasing tensions in the twenty-first century. Ecosystems, especially those already stressed by land use pressures, are particularly vulnerable to rapid climate changes.

Regardless of the different levels of vulnerability and adaptive capacity that future societies are expected to have and the need for regional-level assessments that that implies, all people, governments, and countries should realize that "we're in this together." In all regions, people's actions today will have long-term consequences. Even if humanity completely abandons fossil fuel emissions in the 22nd century, essentially irreversible long-term concentration increases in CO₂ are projected to remain for a millennium or more. Thus, the surface climate will continue to warm from this greenhouse gas elevation, with a transient response of centuries before an equilibrium warmer climate is established. How large that equilibrium temperature increase is depends on both the final stabilization level of the CO₂ and the climate sensitivity.

One threat of a warmer climate would be an ongoing rise in sea level. Warmer atmospheric temperatures would lead to warming of ocean water (and corresponding volumetric expansion) until the heat is well-distributed throughout the oceans — a mixing time known to be on the order of 1,000 years. Instead of only up to a meter of sea level rise over the next century or two from thermal expansion of warmed ocean waters — and perhaps a meter or two more over the five or so centuries after that — significant global warming would likely trigger nonlinear events like a deglaciation of major ice sheets near the poles. That would cause many additional meters of rising seas for many millennia, and once started might not be reversible on the time scale of thousands of years.

**Implications for Climate Policy Choices.** In the face of such uncertainty, potential danger, and long-term effects of present actions, how should climate change policy be confronted? Climate change, like many other complex socio-technical are riddled with “deep uncertainties” in both probabilities and consequences that are not resolved today and may not be resolved to a high degree of confidence before we have to make decisions regarding how to deal with their implications. With imperfect, sometimes ambiguous, information on both the full range of climate change consequences and their associated probabilities, decision-makers must decide whether to adopt a "wait and see" policy approach or follow the "precautionary principle" and hedge against potentially dangerous changes in the global climate system. Since policymakers operate on limited budgets, they must determine how much to invest in climate protection versus other worthy improvement projects — e.g., new nature reserves or clean water infrastructure, education, health improvements etc.

Ultimately, the decision on whether or not to take actions on climate change entails a value judgment on the part of the policymaker regarding what constitutes "dangerous" climate change, ideally aided by complete risk assessments provided by scientists. Cost-benefit analyses (CBAs) are also useful in deciding the ifs and what's of climate change policy, but uncertainties, the need for multiple metrics (e.g., the “fine numeraires”) make this exercise difficult as well, especially when attempting to estimate the costs of surprise and other catastrophic events.

Any policies that are implemented should encourage, and possibly even go so far as to subsidize, technological change. Encouraging technological change through energy policies in particular is of critical importance when addressing climate change, since as Figure 3 showed, alternate energy-technology scenarios make a dramatic difference in the risk of long-term “dangerous” climate change potential.

**Is It Really Too Expensive To Mitigate Global Warming?** Christian Azar and I (Azar and Schnieder, 2002) developed a simple economy model and estimated the present value (discounted to 1990 and expressed in 1990 USD) of the costs to stabilize atmospheric CO₂ at 350 ppm, 450 ppm, and 550 ppm to be 18 trillion USD, 5 trillion USD, and 2 trillion USD respectively (see Azar & Schneider, 2002, which assumes a discount rate of
5% per yr). Obviously, 18 trillion USD is a huge cost. The output of the global economy in 1990 amounted to about 20 trillion USD. Seen from this perspective, these estimates of the costs of abatement tend to create the impression that we would, as critics suggest, have to make draconian cuts in our material standards of living in order to reduce emissions and achieve the desired levels of CO₂ concentration. These same critics view the cost estimates as unaffordable and politically impossible.

However, viewed from another perspective, an entirely different analysis emerges. In the absence of emission abatement and without any damages from climate change, GDP is assumed to grow by a factor of ten or so over the next 100 years, which is a typical convention used in long-run modeling efforts. (The plausibility of these growth expectations is not debated here, but the following analysis will show how GDP is expected to grow with and without climate stabilization policies.) If the 350 ppm target were pursued, the costs associated with it would only amount to a delay of two to three years in achieving this aforementioned tenfold global GDP increase. Thus, meeting a stringent 350 ppm CO₂ stabilization target would imply that global incomes would be ten times larger than today by April 2102 rather than 2100 (the date the tenfold increase would occur for the no-abatement-policies scenario). This trivial delay in achieving phenomenal GDP growth is replicated even in more pessimistic economic models. These models may be very conservative, given that most do not consider the ancillary environmental benefits of emission abatement (see Figure 9 below).

**Figure 9** — *Global income trajectories* under business as usual (BAU) and in the case of stabilizing the atmosphere at 350 ppm, 450 ppm, and 550 ppm. Observe that we have assumed rather pessimistic estimates of the cost of atmospheric stabilization (average costs to the economy assumed here are $200/tC for 550 ppm target, $300/tC for 450 ppm, and $400/tC for 350 ppm) and that the environmental benefits in terms of climate change and reduction of local air pollution of meeting various stabilization targets have not been included. Source: Azar & Schneider (2002).

Representing the costs of stringent climate stabilization as a few short years of delay in achieving a monumental increase in wealth should have a strong impact on how policymakers, industry leaders, and the general public perceive the climate policy debate. Similar results can be presented for the Kyoto Protocol: the drop in GDP below "baseline" levels that would occur if the Kyoto Protocol were implemented ranges between
0.05% and 1%, depending on the region considered and the model used (see IPCC WG III, chapter 8, IPCC 2001c, p. 538). The drops in the growth rates for OECD countries over the next ten years would likely fall in the range of 0.005-0.1 percent per year below baseline scenario projections under the Kyoto Protocol. (It should be kept in mind that the uncertainties about baseline GDP growth projections are typically much larger than the presented cost-related deviations.)

Similar statements could well be made about the costs associated with this bill before the Committee—although I have not myself analyzed it, I strongly suspect that the loss of GDP from the costs incurred would be such a small fraction of typically projected GDP growth rates for the US, that only months of delay in growth would be felt on a base of large increases in personal income. Thus, this bill is likely to be an inexpensive “insurance premium” to slow down global warming and lower the likelihood of “dangerous” climate impacts.

To return to the analysis Azar and I did, assuming a growth rate of 2 percent per year in the absence of carbon abatement policies, implementation of the Kyoto protocol would imply that the OECD countries would get 20 percent richer (on an annual basis) by June 2010 rather than in January 2010, assuming the high-cost abatement estimate. Whether that is a big cost or a small cost is of course a value judgment, but it is difficult to reconcile with the strident rhetoric of some (e.g., Lindsey, 2001, who states on page 5 of this citation that “the Kyoto Protocol could damage our collective prosperity and, in so doing, actually put our long-term environmental health at risk.”) Similar statements about this bill have been made, and have been refuted by careful economic analyses (RFF, 2003; MIT 2003). Clearly, such balanced assessments are what should guide the policy making process.

I thank the Committee for asking for my views on this important piece of legislation.

Stephen Schneider

References:


Lindsey, L.B., 2001: Speech to a colloquium on Science and Technology Policy organized by the American Association for the Advancement of Science (AAAS), May 2001.

MIT 2003 (Integrated Assessment of the McCain/Lieberman bill using the MIT integrated assessment model) (get proper citation)


Resources For The Future (Analysis of McCain/ Lieberman Costs) (get proper citation0


Site References follow (http://www.stanford.edu/~shs):

Austin, D., 1997: “Climate Protection Policies: Can We Afford to Delay?”, World Resources Institute, Washington, DC., see http://www.wri.org/wri/climate/cpp-home.html


Danish Committees on Scientific Dishonesty, 2002: “Decision regarding complaint against Bjorn Lomborg.” Available online at http://www.forsk.dk/uvvu/nyt/udtaldebat/bl_decision.htm


<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Title</th>
<th>Journal</th>
<th>Pages</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoskins, B.J.</td>
<td>2003</td>
<td>“Climate Change at Cruising Altitude?” Science</td>
<td>301: 469-470</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IIASA/WEC</td>
<td>1995</td>
<td>“Global Energy Perspectives to 2050 and Beyond”, World Energy Council, London, see link @ <a href="http://www.iiasa.ac.at/Research/ECS/docs/book_st/node1.html">http://www.iiasa.ac.at/Research/ECS/docs/book_st/node1.html</a></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Lindsey, L.B., 2001: Speech to a colloquium on Science and Technology Policy organized by the American Association for the Advancement of Science (AAAS), May 2001.


Mann, M. and Oppenheimer, M., 2003: “Memo on recent papers by Soon and Baliunas.”


Nesmith, J., 2003: "Foes of Global Warming Theory Have Energy Ties", Seattle Post-Intelligencer, 6/2/03.


<table>
<thead>
<tr>
<th>Name</th>
<th>Title</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearce, F.</td>
<td>“Sit Tight for 30 Years, Argues Climate Guru”</td>
<td>1996</td>
</tr>
<tr>
<td>Prindle, B.</td>
<td>&quot;Bush’s Climate Agreements: Business-As-Usual Widens the Carbon Gap&quot;</td>
<td>2003</td>
</tr>
<tr>
<td>Rahmstorf, S.</td>
<td>“On the Freshwater Forcing and Transport of the Atlantic Thermohaline Circulation”</td>
<td>1996</td>
</tr>
<tr>
<td>Rahmstorf, S.</td>
<td>“Rapid Transitions of the Thermohaline Ocean Circulation - A Modelling Perspective”</td>
<td>1999</td>
</tr>
</tbody>
</table>


Sample, I., 2003: “Not just warmer: it’s the hottest for 2,000 years", The Guardian. 1 September. http://www.guardian.co.uk/print/0,3858,4744226-110970,00.html


<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Title</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schneider, S.H.</td>
<td>1989</td>
<td>&quot;News Plays Fast and Loose With the Facts&quot;, Editorial, Detroit News, 5 December:10A</td>
<td></td>
</tr>
</tbody>
</table>


U.S. Global Change Research Program, 1997: "Key Findings of the IPCC Second Assessment Report", Report by the Subcommittee on Global Change Research, Committee on Environment and Natural Resources, Research of the National Science and Technology Council, A Supplement to the President's Fiscal Year 1997 Budget.


<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Title</th>
<th>Publication Details</th>
</tr>
</thead>
</table>