View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by IssueLab

Congressional Briefing Summary
Spring 2005

Climate Change Post-2100

What are the Implications of Continued Greenhouse Gas Buildup?

Climate Change Post-2100:
What are the Implications of Continued Greenhouse Gas Buildup?

September 21, 2004

PANELISTS

Dr. Berrien Moore III, Director, Institute for the Study of Earth, Oceans, and Space, University of New Hampshire

Dr. Gerald A. Meehl, Senior Scientist, Climate and Global Dynamics Division, National Center for Atmospheric Research, Colorado

Dr. Gerald M. Stokes, Director, Joint Global Change Research Institute, Pacific Northwest National Laboratory and the University of Maryland

The Environmental and Energy Study Institute (EESI) held a Congressional briefing on September 21, 2004 on the climate change implications of exceeding a doubling of carbon dioxide in the atmosphere from pre-industrial levels (prior to the start of the Industrial Revolution). The concentration of carbon dioxide (CO2) in the lower atmosphere, the main heat-trapping greenhouse gas responsible for global warming, is now at its highest level in at least 400,000 years, and likely in the last 35 million years. This concentration stands 32 percent above CO2 levels preceding the Industrial Revolution. Much of the climate modeling reported in the media focuses on the impacts of a doubling of pre-industrial CO2 before the end of this century. However, given current rates of anthropogenic (man-made) CO2 emissions and without policy and technology implementation to significantly reduce these rates, atmospheric CO2 concentrations are unlikely to stabilize at twice pre-industrial levels by 2100. They may eventually reach three to four times pre-industrial levels before stabilization is achieved. Several prominent climate research centers around the world are modeling such scenarios. EESI's briefing featured three leading climate change experts who discussed modeling of these CO2-emission scenarios, their potential impacts, and what would be required to avoid emissions trajectories that lead to a tripling or quadrupling of greenhouse gas concentrations.

Environmental and Energy Study Institute

122 C Street, NW,
Suite 630
Washington, DC
20001-2148
Phone: (202) 628-1400
Fax: (202) 628-1825
www.eesi.org

Carol Werner
Executive Director

EESI....Seeking Innovative Environmental and Energy Solutions

SECTION I: Atmospheric Greenhouse Gas Concentrations Increasing

The atmospheric concentration of carbon dioxide, a major greenhouse gas, is increasing primarily due to increasing fossil fuel use and land use changes. The most advanced climate models indicate that this increase in CO2 concentration will lead to climate change and a number of associated adverse effects (see Box 1). According to Dr. Berrien Moore III, Director of the Institute for the Study of Earth, Oceans, and Space at the University of New Hampshire, reversing this increase is a very challenging problem. Stabilizing emissions does not stabilize the concentration in the atmosphere, and even after achieving stabilization of CO2 in the atmosphere, climate will continue to change, with both ocean and land temperature continuing to rise for decades, and sea levels continuing to rise for centuries. Therefore, the world has a "pre-committed" warming on account of carbon dioxide that humans have already added to the atmosphere.

A great deal of attention has been paid to gathering and analyzing historical data on past atmospheric CO2 concentrations, and their relation to atmospheric temperature. CO2 concentrations have been measured daily in Mauna Loa, Hawaii since 1958. Because

BOX 1: Climate Change Effects

Expected effects of climate change within the century include: increased frequency of drought, wildfires, and heat waves; increased rainstorm intensity, hurricane intensity, and flooding; global melting of glaciers; shifts in and loss of species-specific habitats. Additionally expected are global average temperature increases for hundreds of years; sea-level rise from thermal expansion for over one thousand years; potential melting of the West Antarctic ice sheet which could contribute up to 3 meters to sea level rise; potential melting of the entire Greenland ice sheet which could cause an additional 7 meters rise in sea level; and potential disruption of the global thermohaline (ocean current) circulation, which may cause abrupt climate effects.

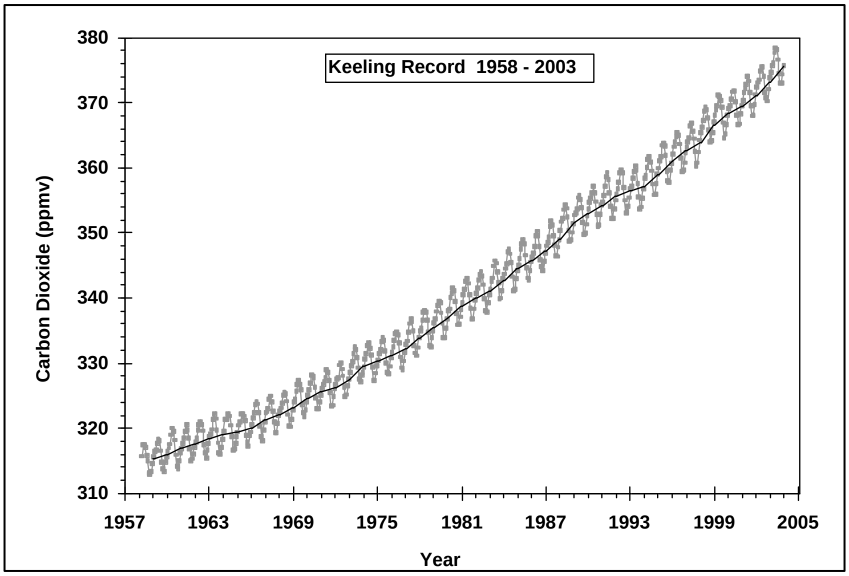


Figure 1. Mauna Loa Monthly Carbon Dioxide Record, 1958-2003 [2]

Mauna Loa is far from major human sources of CO2, it allows a very accurate measure of atmospheric CO2 concentrations. Figure 1 shows CO2 concentrations steadily increasing over time, from 316 parts per million by volume (ppmv) in 1959 to 376 ppmv in 2003, an 18.8 percent increase.[1] The measurements are very accurate—Figure 1 shows the seasonal signal of photosynthetic activity and plant respiration, indicating the natural carbon cycle, as well as the effect of added CO2 from fossil fuel burning and land use change.

Recent ice core records from Greenland give CO2 concentrations from AD1000-2000, with levels at approximately 280 ppmv through the year 1700, then increasing with the advent of the Industrial Revolution. The Vostok ice core provides a 400,000 year record of CO2 concentrations and temperature. As shown by Figure 2 (next page), pre-industrial CO2 concentrations range between 180-280 ppmv, dropping slowly to 180 ppmv during ice ages and then climbing more rapidly to 280 ppmv during interglacial periods. Temperature records reconstructed from the Vostok ice core show there is strong correlation between CO2 and temperature. Scientists do not say dropping CO2 concentrations caused past ice ages. Yet, they observe that when entering an ice age, CO2 decreases as temperature drops, amplifying the cooling. Conversely, coming out of an ice age, CO2 rises as temperature increases, amplifying the warming. As Figure 2 shows, current and projected CO2 concentrations are now moving rapidly above the range of concentrations seen in the last 400,000 years--one must go back 35 million years to find CO2 concentrations the same as current levels. Dr. Moore said that this modern-day increase in CO2 beyond 280 ppmv is not a normal phenomena, and that the Intergovernmental Panel on Climate Change (IPCC) projects further CO2 concentration increases, up to two, three, or even four times pre-industrial values.

> **"We are changing the carbon cycle in extraordinarily fundamental ways"**
>
> ***Dr. Berrien Moore III***

We are currently producing 6.5 billion metric tons of carbon as CO2 per year through the burning of fossil fuel. This number is easy to remember because there approximately 6.5 billion people on planet—so, roughly one ton of carbon is produced per person per year. The United States produces about five tons of carbon per person, while China is now at the world average. Dr. Moore stressed, as mentioned earlier, that stabilizing carbon emissions does not stabilize atmospheric CO2 concentrations. Like a bank account, if we deposit money at a constant rate it still grows. In order to stabilize the atmospheric concentration, we must do "much, much more" than simply stabilize emissions. They must be significantly reduced. Nonetheless, once concentrations are stabilized, climate change continues for many centuries as the planet comes into a new thermal equilibrium.

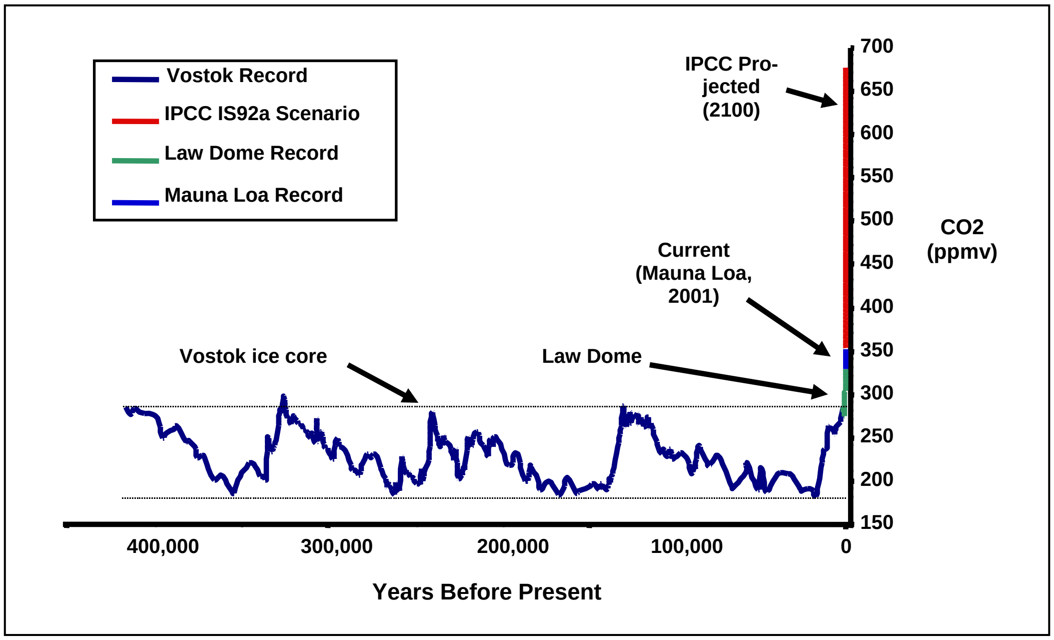


Figure 2. CO2 Concentration in Ice Core Samples and Projections for Next 100 Years

The effects of climate change are already seen today in the Arctic. Studies by the IPCC show Arctic summer sea-ice has declined by more than 30 percent in extent and 30 percent in thickness over the past 50 years. Bright objects like sea ice reflect more sunlight than dark objects like open ocean. So, as sea ice declines, the reflectivity of the planet is fundamentally altered; and as the open ocean absorbs more sunlight, it heats up. Dr. Moore presented two time-lapse climate visualizations,[3] developed by the National Oceanic & Atmospheric Administration (NOAA) and based on climate modeling of a world with CO2 concentrations increasing to two- and four-times pre-industrial levels. Figure 3 shows screenshots for one of the visualizations one, 100, and 300 years after the climate simulation begins. In this case, CO2 concentration increases one percent per year from present-day levels for 140 years. At this point, CO2 concentration reaches a quadrupling of pre-industrial levels, and is then held constant at this level for subsequent years. The visualization shows more rapid warming over the continental regions than over oceanic regions and greater warming in Polar Regions than at lower latitudes, as indicated by the orange and red colored areas. Furthermore, the warming trend continues well past the time at which CO2 concentrations level off. This delayed warming is due to the influence of the world's oceans, which store and release heat over very long periods of time.

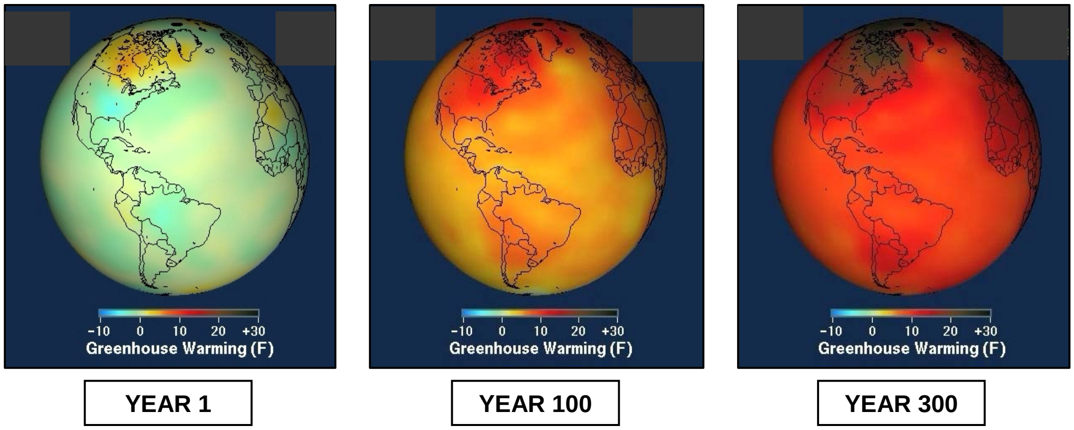


Figure 3. Climate Visualization with CO2 Levels Stabilized at Quadruple Pre-Industrial Levels
(Full color visualization available at http://www.gfdl.noaa.gov/products/vis/gallery/climate_prediction/index.html)

SECTION II: Climate Modeling and Climate Change Commitment

To discuss climate change post-2100 and beyond, we must talk about climate models. According to Dr. Gerald Meehl, Senior Scientist at the Climate and Global Dynamics Division of the National Center for Atmospheric Research (NCAR) in Colorado, top-down climate models represent the state-of-art of our knowledge of what is occurring in the climate system today by using equations from physics and thermodynamics to project climate change dynamics. Climate models are a lot like weather forecasting models, but include interactive ocean, land surface, and sea ice components, and also account for changes in atmospheric constituents like greenhouse gases. One can change model parameters such as aerosols, CO2 and other greenhouse gas concentrations to see what happens.

Dr. Meehl discussed the concept of climate change commitment, addressing the question of how much more additional warming would we be “committed” to if concentrations of all atmospheric constituents were suddenly held fixed. The answer is that thermal inertia in the climate system dictates that the system will continue to warm even if we could stabilize concentrations of greenhouse gases today. Meanwhile, sea levels will continue to rise. He stated that there are policy implications to delaying action in stabilizing GHG emissions, and the longer we wait to take action, the more we commit ourselves to additional warming.

Climate models are used to study the effects of different levels of ozone, solar variations, volcanic eruptions, aerosol effects, CO2, and other greenhouse gas concentrations on the climate system over time. A specific set of assumptions about these levels and their changes over time is known as a “scenario”. Figure 4 shows three current IPCC scenarios for atmospheric CO2 concentration, along with historic data and a hypothetical freeze of CO2 concentration in 2000 and two scenarios that stabilize CO2 concentrations in 2100. The IPCC climate change modeling uses historic data and different CO2, trace gas, sulfate aerosol, and ozone concentration projections based on assumptions about population growth, energy consumption, economic activity, and other variables. These scenarios are selected from 31 scenarios published in the IPCC Special Report on Emissions Scenarios (SRES) to illustrate how much more climate change could occur in each case.

Changes in CO2 and other greenhouse gas concentrations in the model drive changes in climate. Measured atmospheric CO2 concentrations have increased from 280 ppmv in the late 1800's to 365 ppmv in 2000, with observed atmospheric warming of 0.6°C over this time. Even if we were to freeze CO2 concentrations today, the model projects we would still be committed to another 0.5°C warming, or an additional 85 percent, by 2100 compared to 20th century climate change. The low estimate for future CO2 increase is illustrated by scenario B1, which results in warming of roughly an additional 1°C by 2100 and another couple tenths of a degree by 2200 if concentrations could be stabilized at year 2100 values. A higher estimate for future CO2 increase (scenario A1B) results in warming by about 2°C by 2100 and another three tenths of a degree (or so) by 2200. Scenario A2 represents a “business-as-usual” emission path and results in much greater CO2 concentrations and additional warming. Globally, more warming is expected at high northern latitudes and less over the southern oceans.

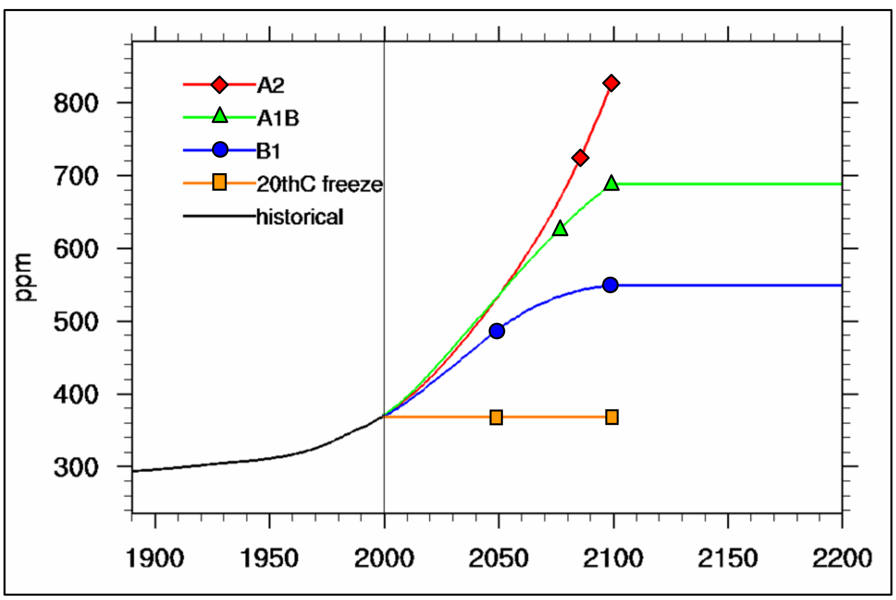


Figure 4. IPCC CO2 Concentrations, 1900-2200

During the 20th century, globally averaged warming was about 0.6°C, but didn't occur uniformly at all locations in the model or observations. The model shows cooling in the upper Midwest over the 20th century, which agrees with actual observations. However, by the end of the 21st century, the model projections indicate there would be unambiguous warming across the United States. Some believe global warming could lead to slowdown of ocean thermohaline circulation (THC), producing regional cooling effects, such as in northern Europe. The thermohaline circulation is a series of ocean currents that transport nutrients and thermal energy throughout the world's oceans. While the model shows some weakening of thermohaline circulation to date, and continued weakening through 2100, it does not show cooling in the higher latitudes of the northern hemisphere. While heat transport from the tropics to high latitudes may be reduced, atmospheric warming from greenhouse gases overpowers effects of reduced overturning of circulation in the Atlantic. Dr. Meehl added that the model does not include ice sheet dynamics, and therefore cannot model effects of ice sheet collapse or other potential mechanisms for catastrophic shutdown of THC.

The model includes sea level rise from thermal expansion of the oceans as they warm. This is a serious issue with regard to climate change commitment, as sea levels will rise for centuries after atmospheric carbon dioxide is stabilized due to the slow thermal response of the deep ocean. As Figure 5 illustrates, at the year 2000, the model projects we are already committed to nearly an additional 10 cm sea level rise by 2100--over and above the 3.5 cm rise already seen due to thermal expansion in the 20th century. After 2100, even upon having stabilized CO2 concentrations at 550 ppmv by 2100 (the conservative B1 scenario), we would be committed to an additional 20 to 30 cm sea level rise by 2300. This does not include potential ice sheet melting, which could roughly triple these conservative estimates due to thermal expansion only.

There have not been many models run with CO2 concentrations increasing beyond 2100. The National Center for Atmospheric Research modeled continued CO2 increases through 2200, up to roughly three to four times pre-industrial CO2 concentrations of 280 ppmv. The model found that increasing CO2 to 710ppmv in 2200 leads to global warming of an additional 2.0°C by end of 22nd Century; and increasing CO2 to 1114 ppmv in 2200 (roughly 4x CO2) leads to global warming of an additional 3.4°C and thermohaline circulation decline of 21 percent by end of 22nd Century. Again, temperature increases are highest at high latitudes, with increases up to 6-8°C at high latitudes and 3-4°C over the United States.

Climate models can also be used to provide information on changes in extreme events such as heat waves. Heat waves affect human mortality and have economic, ecosystem and wildlife impacts. Heat wave severity can be defined as the mean annual 3-day warmest nighttime minima event, which has been correlated with mortality. The modeling presented by Dr. Meehl matched "surprisingly well" with present-day heat wave severity, such as the 1995 Chicago heat wave. In a future warmer climate, modeling indicates heat waves become more severe in southern and western North America, and in the western European and Mediterranean regions. Heat waves already occur in the Southern and Southwestern United States, so many people have adapted through actions such as installing air conditioning. Dr. Meehl said that in this case, increased heat waves may have more economic than human health effects, such as increased energy bills from more air conditioning and increased stress on the power grid. However, in areas not already used to heat waves such as the Northwestern United States, there actually may be larger impacts for humans and wildlife and ecosystems because adaptation has not happened.

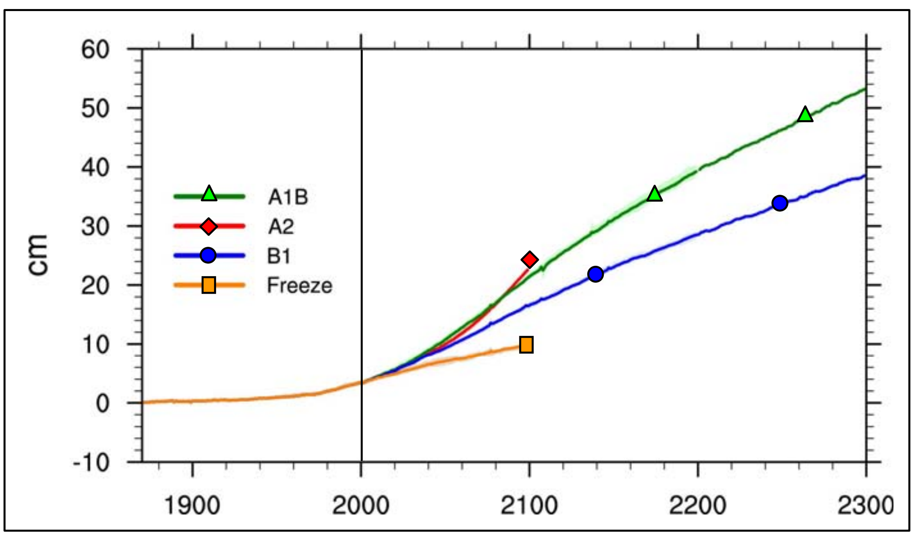


Figure 5. Global Sea Level Change, 1900-2300

In summary, Dr. Meehl said advanced global coupled climate models can be used to estimate future climate change, including climate change commitment, using various scenarios of increasing greenhouse gases over the next few centuries. Due to thermal inertia of the climate system, even if concentrations of greenhouse gases can be stabilized at some point in time, we are already committed to more warming and rising sea levels in the future. Regional changes in extreme events, such as heat waves, will give rise to some of the largest impacts due to increasing greenhouse gas concentrations.

> **"Even if we were to freeze CO2 concentrations today, [climate] models project we would still be committed to about another 0.5°C warming, or an additional 85 percent, by 2100."**
> ***Dr. Gerald Meehl***

SECTION III: Stabilizing Carbon Dioxide Concentrations

What is the likelihood that we will see high CO2 scenarios? Dr. Gerald Stokes, Director of the Joint Global Change Research Institute at Pacific Northwest National Laboratory and the University of Maryland, began by saying that for carbon dioxide, stabilizing emissions is not enough. We must stabilize atmospheric concentrations, not emissions. To stabilize concentrations, emissions of CO2 must peak and then decline--essentially to zero after a number of centuries. Humans emit over 6 billion tons of carbon per year from fossil fuels and land clearing. Fossil fuels are used for transportation, electric generation, and a wide range of industrial, commercial, and residential uses. Under a "business-as-usual" (BAU) scenario, where present energy use trends continue and no unforeseen policy or technology changes are made, CO2 emissions will roughly triple by 2100. At the same time, BAU leads us to roughly triple pre-industrial CO2 concentrations by 2100, to just over 700 ppmv.

There are two major technological challenges in stabilizing carbon dioxide concentrations. The first is maintaining the current rate of technical innovation--the "business-as-usual" rate of innovation--in reducing the amount of energy used per unit of economic output. If we made no more technology improvements (i.e., ceased innovation as usual), CO2 emissions would be roughly **10** times current emissions, and concentration would be **four** times pre-industrial levels by 2100. Thus, an extraordinary improvement in reducing emissions is already built into BAU, for BAU assumes innovation as usual.

Half the reduction from this "frozen technology" scenario comes from demand reduction through continued energy efficiency improvements and restructuring of the economy. The other half comes from continued carbon reductions in the energy sector through increased use of renewable energy such as solar, wind, geothermal, and conventional biomass, as well as efficiency improvements in fossil and nuclear energy technologies. This first set of reductions is driven by the market and not climate policy.

However, these BAU carbon reductions do not fix the climate problem. While "innovation-as-usual" significantly reduces carbon emissions from what they would have been with no additional innovation, emissions still increase, as do atmospheric carbon dioxide concentrations. The climate challenge lies in addressing the "stabilization gap", which is the difference between BAU with innovation and the emission trajectory required to stabilize atmospheric concentrations of CO2. According to Dr. Stokes, tremendous additional technological advances in a wide range of energy technologies are required, including:

- Additional energy efficiency improvements
- Additional demand reduction
- Advanced biomass technologies
- Additional solar, wind, geothermal, and other renewable energies
- Soil sequestration of carbon
- Hydrogen with geological carbon sequestration
- Fossil-fueled power with geological carbon sequestration
- Additional nuclear power

Climate mitigation technologies must compete for market share and need market signals. Dr. Stokes said we currently know of no climate mitigation silver bullet--there is no single solution. Today's world is very heterogeneous, with many energy technologies and many fuels, and this will continue into the future. Which technologies deploy, at what rate, and to what extent will unfold over time. Climate stabilization technologies are unlikely to penetrate the market without a specific signal that GHG emissions must be reduced. There are many policy options to generate such a signal. For example, Norway has put a tax on CO2 emissions which has led to a geological carbon sequestration project. "Cap-and-trade" policies are not a tax *per se*, but allow the market to decide how best to find solutions. However, Dr. Stokes stressed that technology alone will not necessarily stabilize CO2 concentrations. For example, we could have a fossil fuel-based hydrogen economy and carbon capture and sequestration technology available. Yet, without climate policy, we could still have increasing CO2 concentrations.

The scale of the needed climate change mitigation is hard to grasp--the combustion of fossil fuels is one of the largest industries, if not the largest, on the planet by mass. Annual current global emissions (not including deforestation) are 6.6 gigatons of carbon, or 24.2 gigatons of carbon dioxide. A gigaton is equal to one billion tons, or more than the mass of all humans on the planet (see Box 2, next page). This is in comparison to the global reservoirs of carbon--the atmosphere currently holds 750 gigatons, standing biomass holds 650 gigatons, and terrestrial soil holds 1500 gigatons of carbon. The increase in the atmosphere since the pre-industrial period is 200 gigatons of carbon.

Dr. Stokes said the climate problem will likely be addressed in two stages—near-term and longer-term solutions. Transitional technologies that may provide near-term relief include: terrestrial sequestration, such as tillage practices that leave more carbon in the soil; energy efficiency improvements, which are ultimately limited by the second law of thermodynamics; renewable energy without storage, perhaps limited to 20 percent market penetration; nuclear power without fuel reprocessing, perhaps to 2050; and CO2 capture and geological sequestration, which could potentially provide a few centuries of storage in certain regions of the world.

As longer-term solutions, Dr. Stokes included: nuclear fusion, which still lies many decades in the future; biotechnology to mimic biological energy production, which may appear sooner than we think; renewable energy with storage to go beyond a 20 percent penetration; and a restructuring of energy demand through methods such as urban and transit planning. Dr. Stokes noted that the decentralized nature of the US population results in a lot of vehicle travel compared to other countries, and that every gallon of gasoline burned equals five pounds of carbon put into the atmosphere.

> **"For carbon dioxide, stabilizing emissions is not enough; we must stabilize atmospheric concentrations, not emissions."**
>
> ***Dr. Gerald Stokes***

In a recent publication, Princeton scientists Pacala and Socolow[4] state that "humanity already possesses the fundamental scientific, technical, and industrial know-how to solve the carbon and climate problem for the next half-century. A portfolio of technologies now exists to meet the world's energy needs over the next 50 years and limit atmospheric CO2 to a trajectory that avoids a doubling of the pre-industrial concentration." Their paper defines the problem of climate stabilization as reducing annual emissions by seven gigatons of carbon, and coins the term "wedge" to denote reduction of one gigaton of carbon. The paper identifies 15 such "wedge" technologies or actions, seven of which are needed.

Dr. Stokes discussed five of these wedges, noting that it is "sobering" to consider the magnitude of this stabilization effort, and that while these technologies exist, they are not necessarily economic at this time. Table 1 (below) lists the five wedges considered, with commentary from Dr. Stokes, who said, "these are interesting ideas....[and] give some sense of the scale of the change we are in fact talking about."

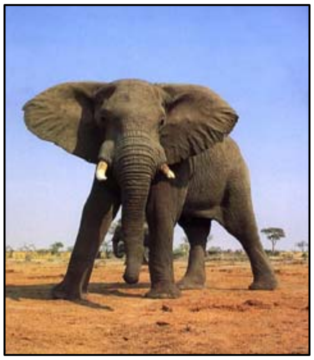
Not all climate solutions will work everywhere. Some have advantages over others in different parts of the world, and even within countries. For example, Dr. Stokes said a hydrogen economy in the United States will likely be tied to geological carbon sequestration if the hydrogen is derived from fossil fuels such as coal or natural gas. The question of where carbon would be sequestered then must be addressed. Potential geologic features include unmineable coal seams, depleted oil and gas basins, and deep saline formations. Dr. Stokes said there are some geographic mismatches between potential capture and storage sites and existing power plants. The problem is even more difficult in addressing mobile carbon emission sources such as motor vehicles. Globally, CO2 storage capacity is a very heterogeneous natural resource. The United States is the "Saudi Arabia" of sequestration capacity, while China and Japan, for example, have limited resources. The price and availability of carbon sequestration as a part of the solution varies significantly with geography.

In addressing the challenges of keeping CO2 concentrations at the level that, in the words of the UN Framework Convention on Climate Change (UNFCCC), prevents 'dangerous interference' with the climate system, Dr. Stokes said, "We cannot forget that the scale of the problem is huge." The solutions will require a 'technology revolution' if not two, and such technologies must not only be technically feasible but economically viable. In other words, they must be able to compete with other technologies on the open market. He said further that every person on the globe and every sector must contribute to climate change mitigation efforts. Solutions must be tailored to different regions. For example, Brazil has more solar radiation than high-latitude nations, making it a good

Box 2. How Large Is a Gigaton?

Just one gigaton is a lot. A gigaton is:

- Greater than the mass of all the humans on the planet.
- Greater than the annual global production of iron and steel.
- The mass of 2740 Empire State Buildings, or 77 Empire State Buildings made out of solid lead.
- The mass of 142,857,142 African elephants. (That's enough elephants stacked on top of each other to reach from Earth to the moon and halfway back.)



It takes 143 million African elephants to make a single gigaton!

location for growing biomass. With respect to climate policy, Dr. Stokes observed that investing in climate action now is similar to purchasing insurance. By taking action, we would pay now for (potentially undefined) benefits later. He said the real costs won't be fully known until we are well into an emissions mitigation regime, and noted that sulfur dioxide mitigation in the United States costs far less than economists anticipated. Additionally, there may be innovations we don't expect. Dr. Stokes closed by saying, "Regardless of the scale of innovation and regardless of the scale of cost, if we are going to stabilize atmospheric carbon dioxide concentration, it is a massive transformation of the energy system, and perhaps two massive transformations."

CONCLUSION

The three panelists addressed a problem facing mankind that is far greater in scope and in scale than humans have perhaps ever before faced. In examining the long-term effects of actions we have taken to date--the "climate change commitment" already in the system from our carbon dioxide emissions over the past century--we must realize that actions we take today and in the next few decades will have significant ramifications for the path of the future climate, the well-being of humans, and all the natural and ecological systems that support them throughout the world. As the climate modeling and climate visualizations have shown, the ocean-climate system will return the effects of human carbon emissions to date for many centuries. Even stabilizing climate at a doubling of pre-industrial CO2 concentrations--which we are almost certain to surpass--may lead to significant climate change. Without concerted political will and commensurate policy action, there is a good chance the world will see a tripling or greater of CO2 concentration by the end of this century. The effects of such an atmospheric change should not be underestimated. Just like a supertanker running at full speed, to change the trajectory of the climate change we have put in motion, we must begin to take action now if we are to alter the future course. In the short time since this Congressional briefing was held in Washington DC, the Kyoto Protocol to the UNFCCC has been ratified and has entered into force; the Arctic Climate Impact Assessment, which details a number of significant climate change effects being observed now in the Arctic, has been published; and a number of bills related to climate change and greenhouse gas mitigation have been introduced in the 109th Congress. This briefing identified the scientific evidence for climate change, the implications of continued greenhouse gas buildup in the atmosphere, and the magnitude of the effort that will be required to address the challenge of climate stabilization. We hope that policymakers take this message to heart, and muster a strong, concerted, and sustained bipartisan effort to effectively, economically, and rapidly address this challenge.

ENDNOTES

1 Since the briefing the Climate Monitoring Diagnostics Laboratory (CMDL) of the National Oceanic and Atmospheric Administration (NOAA) reports that atmospheric concentrations of the greenhouse gas carbon dioxide reached an all-time high in 2004 at 378 parts per million (ppmv). http://www.cmdl.noaa.gov/publications/annualmeeting2004.html

2 Data from Keeling, C.D. and T.P. Whorf. 2004. Atmospheric CO2 records from sites in the SIO air sampling network. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. http://cdiac.esd.ornl.gov/trends/co2/sio-mlo.htm

3 The climate visualization "Temperature Response to Increased Atmospheric CO2" is available from the NOAA Geophysical Fluid Dynamics Laboratory at http://www.gfdl.noaa.gov/products/vis/gallery/climate_prediction/index.html and discussion of the visualization and related climate modeling are available at http://www.gfdl.noaa.gov/~tk/climate_dynamics/climate_impact_webpage.html

4 Pacala, S. and R. Socolow. 2004. Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies. Science, Vol. 305:968-972. http://www.princeton.edu/~cmi/resources/stabwedge.htm

Writer: Fredric A. Beck, Senior Policy Associate

Editor: Carol Werner

Special thanks to Jay Harris and the Changing Horizons Fund of the Rockefeller Family Fund for their support of this briefing. Please see the EESI website at www.eesi.org for electronic versions of each of the speakers' presentations, as well as the electronic version of this publication and other EESI briefings on climate change. A DVD of the briefing may also be ordered through EESI.

For more information please contact Fredric Beck at (202) 662-1892 or fbeck@eesi.org.