Beyond Science:
The Economics and Politics of Responding to Climate Change

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Conference Report

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Abstract

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Preface

As the world's largest consumer of hydrocarbons and a leading emitter of greenhouse gases (GHGs), the United States must play a key role in any global effort to combat climate change. American scientists have been at the forefront of the emerging consensus view on the human role in climate change, yet U.S. policymakers, politicians, academics, and the media have struggled to fashion a concrete response. So far, climate change policies have been piecemeal and relatively ineffective.

Climate change is ultimately a political problem made all the more difficult by challenges that will persist for generations to come. The scope and complexity of the issue demands an equally diverse and multidimensional response. Whatever its final form, a comprehensive strategy will require global cooperation on a scale never before achieved in history.

An effective U.S. climate policy must consider the threats that extreme weather, rising ocean temperatures, and shifts in rainfall patterns will pose to human life and basic infrastructure. It must also address the economic impacts and social implications of severe climatic events as well as the costs and benefits of policy responses to GHG emissions. In addition, sound policy should anticipate how changing climate may affect relations between nations and their willingness to work together to overcome climate change. Finally, an effective climate policy must consider issues related to national security. The United States has 63 coastal military facilities threatened by sea level rise and severe weather events. The U.S. military will be increasingly challenged by a larger number of humanitarian disasters and refugee crises. Moreover, the melting of the Arctic has rekindled competition for territory and trade routes in this geographic tip of the northern hemisphere.

In the United States, where state and federal interests can differ, the policy response to climate change has so far been highly complicated and politically charged. Individual states and municipalities have taken independent paths that are sometimes at odds with federal policies or initiatives. The next U.S. administration must address this policy conundrum if it is to forge a more effective response and achieve a unified approach to global climate change, both at home and abroad.

To examine climate change issues from a policy and scientific perspective, the Science and Technology Policy, Energy Forum, and Health Economics programs of the James A. Baker III Institute for Public Policy, together with the Energy & Environmental Systems Institute and the Shell Center for Sustainability at Rice University, hosted a conference on February 9, 2008, titled "Beyond Science: The Economics and Politics of Responding to Climate Change." The event, supported by the Science & Innovation Section of the British Consulate-General in Houston, sought to highlight the challenges and opportunities for developing a more effective U.S. climate policy. More than a dozen top leaders in science, public policy, economics, and business participated in the event, including U.S. Senator John Kerry of Massachusetts, who served as the keynote speaker for the event. The conference discussions and presentations embodied the core science, economic, social, and business challenges that must be addressed to devise a sound public policy response to climate change. Conference participants discussed policies that have been adopted or are under consideration in the United States, as well as the background data needed to assess the effectiveness of these policies and other options.

Among the topics covered were the Intergovernmental Panel on Climate Change (IPCC) 2007 Assessment Report; mitigation and adaptation strategies; policy approaches to limiting carbon emissions and the economic issues related to such policies; and technology options for dealing with climate change. The event drew more than 350 policymakers, scientists, economists, opinion shapers, business leaders, and interested citizens to the Baker Institute. This conference report is a summary of the findings and discussions.

I. Introduction

Climate change is one of the greatest challenges facing mankind today. Its global scope and multigenerational scale make it “uniquely daunting among public policy challenges,” Baker Institute founding director Edward Djerejian said in an opening address to conference participants. Djerejian emphasized that climate change “demands response at both the supranational level—through institutions, for instance, such as the United Nation’s Intergovernmental Panel on Climate Change… and on the subnational level as well—through state and local governments.” The issue thus requires the active involvement of government, academia, business, and civil society.

In his keynote address, “The Road from Bali: The Future of American Policy on Global Climate Change,” Kerry stated that the threat of climate change was “truly grave and significant,” and called for immediate steps to deal with it. “When I ran for president,” Kerry said, “I and many others spoke about the need for our foreign policy to once again be restored to a foreign policy that ‘stops at the water’s edge.’ Now we are literally considering policies that stop the water at the water’s edge.”

Kerry recalled James Baker’s first public address as secretary of state in 1989, in which Baker warned that “time will not make it [climate change] go away.” “Those words of Jim’s ring truer than ever," Kerry remarked. "Time has not made the problem go away. On the contrary, time has obviously accelerated the consequences of this issue."

The continued construction of coal-powered generation plants in the United States, China, India, Mexico, and South Africa means that "we're adding [greenhouse gas emissions] at a rate that is reaching the danger curve at a much faster scale. And that's why it is so utterly compelling for us to move," Kerry said.

Kerry noted that, unfortunately, members in the U.S. Senate still disagree on the science behind climate change. "We actually have a flat earth caucus … we are struggling with people … who either believe it is a conspiracy … or that it's one of those ginned-up … political issues." Arguments against taking action include the expense and the idea that "the Chinese aren't doing anything … so why should we? I call it the ostrich policy," Kerry said. But he believed that a sound carbon policy can be achieved in the United States and that industry was starting to support the effort because "they want certainty in the marketplace." "I have an inherent faith in America, in our ingenuity, in our creativity, in our entrepreneurial capacity, and I know what happens when we put our mind to a task … of finding alternative fuels and generating new technologies. This is going to take off," he said.

Kerry noted that several U.S. states have imposed restraints on carbon emissions and that the U.S. Congress plans to take the lead on climate change regulation through a national cap-and-trade system to manage greenhouse gas emissions (GHGs). He believed that the cap-and-trade plan would be debated in coming months and that several legislators were working to "create the strongest lobbying effort." Senators Joseph Lieberman (ID-CT) and John Warner (R-VA) are part of a growing bipartisan coalition of lawmakers who support climate legislation, he said.

"America's Climate Security Act," introduced by Lieberman and Warner, may be the most viable climate change bill to be introduced since the 2006 congressional elections. The Lieberman-Warner bill proposed the creation of an auction-based, cap-and-trade system to reduce GHG emissions to 19 percent below 2005 levels by 2020 and to nearly 70 percent below 2005 levels by 2050. Auctioned credits would rise from 23 percent in 2012 to 73 percent in 2031.

Under the cap-and-trade program, emissions allowances would be set at progressively lower levels each year between 2012 and 2050, and companies would be permitted to trade emissions allowances in a market-based system.

"If we can get the target out there, create the framework, let the private sector know with certainty what the standard is, then the science is going to move even more rapidly and the technology will move even more rapidly," Kerry observed. He added that regulation is necessary because "we have seen that voluntary reductions don't work."

Kerry said he favored a cap-and-trade system over a carbon tax because the latter does not necessarily lead to lower GHG emissions. "My own belief is that a carbon tax doesn't do it, because you still have to have the reductions," he said. "And if you put a tax on carbon, that doesn't automatically mean you're going to reduce. It just means you're going to get revenue." Kerry admitted that a cap-and-trade system is "taxing through the backdoor." But, he added, it is the most effective way to tax because it allows the market to set the carbon price needed to achieve the targeted GHG reduction.

As lieutenant governor of Massachusetts in the 1980s, Kerry helped design a cap-and-trade system for sulfur to reduce the incidence of acid rain. Citing this experience, he urged Americans to remember the idea has worked well before and could spur innovation by U.S. industry. He also noted the success of the Montreal Protocol on chlorofluorocarbons (CFCs) and the role technology innovation played to protect the ozone layer. [1]

Kerry further stressed the need to reach out to more countries, since the United States is one of the largest carbon emitters in the world. As a member of the U.S. congressional delegation at the 2007 United Nations (U.N.) Climate Change Conference in Bali, where participants began creating a roadmap to help negotiate a post-Kyoto protocol, Kerry repeatedly heard that the United States should take an active role in shaping climate change policy. "Every person I met

[1] Additional information on the Montreal Protocol can be found online at http://www.afeas.org/montreal_protocol.html.

with said 'we need the United States to lead,'" Kerry said. "And the minute we [do], and our marketplace begins to shift—believe me—others will come on board."

Kerry believed that the "Bali Roadmap" marked real progress toward a post-Kyoto vision. It recognized the importance of the four building blocks of fighting climate change: mitigation, adaptation, financing, and technology. Most importantly, the roadmap represents the groundwork towards a final agreement in 2009, when a new protocol will be needed. "The whole thing is going to hang on several words that came out of Bali …'shared but differentiated responsibility' … That is what's going to give life to our movement forward on global climate change," he said. Other countries that had resisted calls for action in the past, including China and Australia, are now much more engaged, Kerry believed.

In response to a question about the U.S. Senate's rejection of the Kyoto accord in 1997, Kerry said it was "a very complicated parliamentary situation"; the Senate wanted American participation, but only if less-developed countries were part of the plan. The Senate unanimously passed a resolution stating the United States would not be party to any agreement that did not include emission targets for developing countries or which caused serious harm to the U.S. economy. Fearing certain rejection, the Clinton Administration never submitted the Kyoto Protocol to the Senate for ratification. The Congress hoped, perhaps unrealistically, that subsequent international negotiations would permit changes to the protocol that would make ratification possible.

"We took the position, with the 95-to-nothing vote on the floor of the Senate, that we need to get the less-developed countries involved, and thereby avoided a rejection of Kyoto altogether, expecting a president responsibly to say 'now, I am going to go back to the table and negotiate, and we're going to get the less-developed countries in, and we'll use the framework of Kyoto and go forward,'" Kerry said. The United States was never able to negotiate such concessions or attain an acceptable starting point for judging its own base line. As a base line year, 1990 was thought to greatly disadvantage the United States while allowing Europe to grandfather the closure of inefficient Eastern European facilities. These problems were among the reasons President George W. Bush rejected the accord in 2002.

U.S. leadership is the key to gaining international cooperation on climate change policy, the former Democratic presidential nominee believed. If no investment is made today, we will pay significantly higher costs in the future. Taking action today is "a smart investment," Kerry said. "When you measure it against what we spend in Iraq, it's a trivial amount of money."

The investment is a win-win situation compared to the alternative, Kerry concluded. "If we're wrong … we're going to create jobs, we're going to have a clean economy, [and] we'll be sustainable. We'll have found alternative fuels and have greater security because we're not dependent on Middle East [oil]," he stated. "What's the downside if they are wrong? Catastrophe, as we know it."

II. The Science of Climate Change

Timothy Killeen, director of the National Center for Atmospheric Research (NCAR), presented findings from the Intergovernmental Panel on Climate Change 2007 Assessment.[2] The Intergovernmental Panel on Climate Change (IPCC) is a group of over 1500 scientists which help assess the scientific, technical, and socio-economic literature relevant to understanding climate change. In 1990, the IPCC gave the world the first broad overview of climate change. Since then, it has released four increasingly assertive assessments including the most recent report in 2007 (see Figure 1: Science and Society).

[2] "IPCC, 2007: Summary for Policymakers," in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, S. Solomon et al., eds. (Cambridge, U.K. and New York: Cambridge University Press), http://www.ipcc.ch/ipccreports/ar4-wg1.htm.

Figure 1: Science and Society - The IPCC Sequence

- IPCC (1990)-Broad overview of climate change science, discussion of uncertainties and evidence for warming.
- IPCC (1995)-"The balance of evidence suggests a discernible human influence on global climate."
- IPCC (2001)-"Most of the warming of the past 50 years is likely (>66%) to be attributable to human activities."
- IPCC (2007)-"Warming is unequivocal, and most of the warming of the past 50 years is very likely (>90%) due to increases in greenhouse gases."
- AGU Statement (2008)-"The Earth's climate is now clearly out of balance and is warming."

Source: Timothy Killeen, National Center for Atmospheric Research.

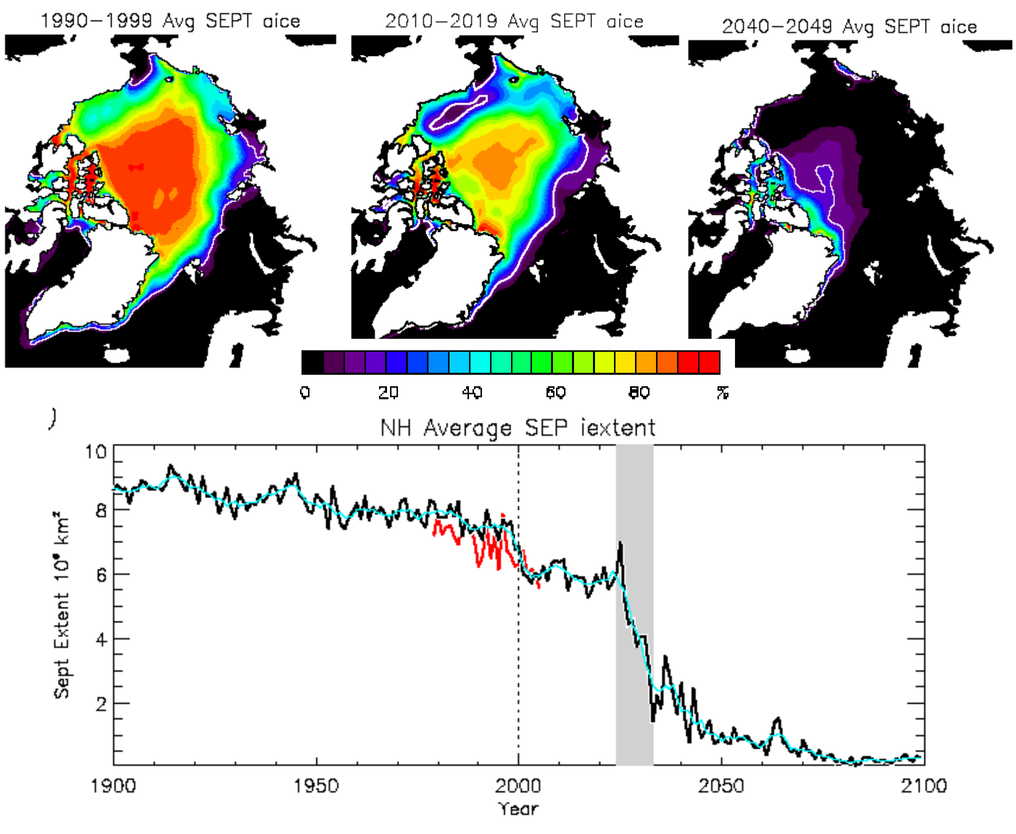
In his talk titled "Intergovernmental Panel on Climate Change 2007 Report and Climate Change Modeling," Killeen noted the conclusion of the report: "Warming of the climate system is unequivocal, as is now evident from observations of increasing global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level." Based on the data and modeling, the IPCC concluded that it is likely the average global temperature will rise 0.2°C over the next two decades and 2-4.5°C by 2050, he said. "Even if we find a way to stabilize greenhouse gas concentrations at current levels, we will still see continued global warming and, for example, sea level rise for centuries due to the time scales associated with climate processes and feedbacks," Killeen said.

Killeen described some negative impacts of the current warming trend. He presented the NCAR models, which postulated that by 2040, 80 percent of summer Arctic ice will have disappeared, and the Mount Kilimanjaro ice cap will be gone (see Figure 2: NCAR Simulations). The negative impacts on human health include problems due to extreme climatic heat and changes in water availability, increases in respiratory ailments, and vector-borne as well as water-borne diseases, resulting in the strong possibility of significant numbers of environmental refugees.

We are not "beyond science" as the conference title suggests, Killeen argued; science, in fact, is a necessary and important part of the solution. "Science has to step up and not just write papers and develop projections, but actually get involved in decision- tool generation, in planning, in iterative design of how society is going to function," he declared. Science will be vital in the search for improved climate models, the best adaptation methods, and the development of technologies that will reduce GHG emissions, he added.

Killeen further argued that "we are failing in our general education of people who can solve these problems." In 2000, for example, there were approximately 4,000 geosciences graduates in the United States, while over 6,000 jobs were available in the oil and gas industry alone. Killeen stressed that the U.S. education system should include a broader range of geosciences materials, and he advocated adjusting National Science Education System content standards for high schools to achieve that end.

Figure 2: NCAR Simulations: A Door Ajar! Abrupt Transitions in the Summer Sea Ice



Red=Observations; **Blue**=5-year Running Mean; **Black**=Simulated.

Source: National Center for Atmospheric Research.
Note: Gradual forcing results in abrupt September ice decrease; extent decreases from 80 percent to 20 percent coverage in 10 years.

Criticizing the misrepresentation of climate change to the public, Killeen proposed that scientists and the media were having difficulty communicating effectively. Killeen noted that, in one recent survey, 90 percent of scientists thought few members of the media understood the nature of science and 66 percent said most press members have no idea how to interpret scientific results, while 62 percent of the reporters surveyed thought scientists could not communicate effectively. This gap in communication has meant that climate myths that have been disproven for years are still prevalent, Killeen argued. Citing a common example, Killeen referenced a commonly held notion that only the surface temperature, not the free troposphere, is warming, but recent data analysis has disproved this premise.

Furthermore, theories that the sun is causing the currently observed changes in global warming and cooling trends have been similarly refuted since the sun has not changed in sufficiently significant ways in recent decades (in terms of its brightness, cosmic rays or length of cycle). Killeen also disputed the view that global warming will have mainly positive impacts on society by, for example, leading to longer growing seasons in mid-latitude areas. He mentioned that such positive effects will be offset by many negative effects, especially in developing countries which have limited water availability or are located at low sea level.

Killeen concluded that "it really is ours to decide where we end up at the end of the century." He encouraged scientists to participate with economists and policymakers to help achieve positive changes.

III. Addressing the Impacts of Climate Change: Mitigate, Adapt, or Suffer

In 2007, the U.N. Foundation and Sigma Xi[3] published a report, *Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable*,[4] which addressed the policy implications of ongoing climate science. This U.N. Scientific Expert Group (UNSEG) report

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[3] Sigma Xi is an international, multidisciplinary, nonprofit scientific research society of approximately 60,000 members that promotes science.

[4] Scientific Expert Group on Climate Change, *2007: Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable*, R.M. Bierbaum et al., eds. (Research Triangle Park, NC: Sigma Xi and Washington, DC: United Nations Foundation, Washington, DC), http://www.unfoundation.org/press-center/publications/confronting-climate-change.html.

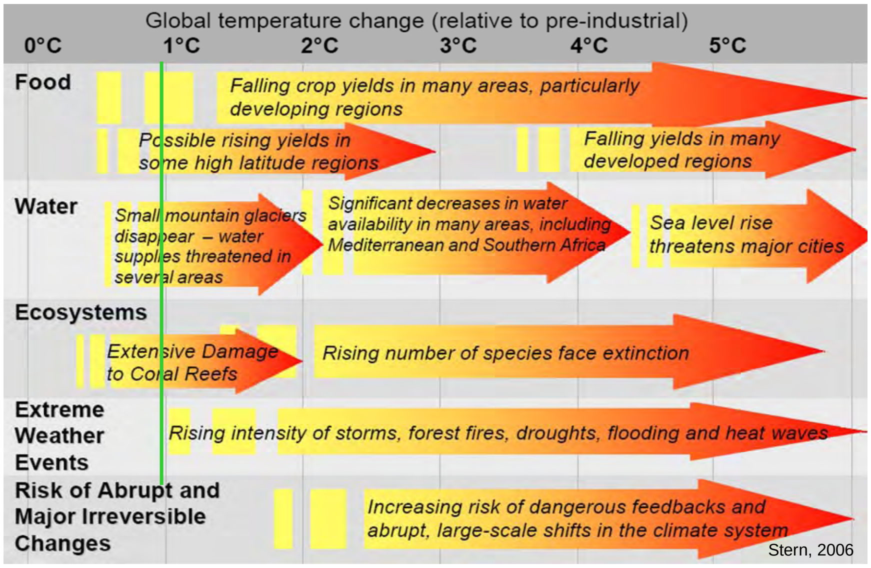
identified technology, policy, and institutional changes that will facilitate both mitigation of and adaptation to climate change and enable society to respond to sea level rise and extreme changes in climate and weather patterns across the globe. Discussing the findings of this report were two of the report's coordinating lead authors: John Holdren, the Teresa and John Heinz Professor of Environmental Policy at Harvard University and director of the Woods Hole Research Center, and Rosina Bierbaum, dean of the School of Natural Resources and Environment at the University of Michigan.

Holdren presented the report's recommendations on mitigation in his talk "The U.N. Scientific Expert Group Recommendations on Mitigation: How to Avoid the Unmanageable Climate Disruption." He began by noting that both mitigation strategies (i.e., taking steps to reduce the magnitude of the changes humans are causing such as reducing GHGs) and adaptation strategies (i.e., taking steps to reduce the effects of climate change such as building dikes) must be employed. Otherwise, human suffering from climate change will not be averted. Holdren added that mitigation policies alone would be insufficient since it is already too late to avoid substantial climate change. But, he added, adaptation-only measures would become more costly and less effective if GHG emissions continue without restraint. This is especially true in light of the high level of emissions predicted for the coming decades under a business-as-usual approach to global energy consumption.

While there is no silver bullet strategy, a "silver shotgun approach" could include both mitigation and adaptation strategies, Holdren remarked. "Integrated strategies for mitigation and adaptation together clearly can drive investment and growth in a whole variety of ways," he said.

Holdren called for an array of mitigation strategies to keep the Earth's temperature from rising past the "tipping point"—described as 2-2.5°C above what it was in 1750 or atmospheric carbon dioxide (CO_2) levels over 450-500 parts per million (ppm). According to the IPCC 2007 assessment, 2005 CO_2 levels were at 379 ppm with a growth rate of 1.9 ppm/year. Past the tipping point, climate change could have a major and possibly irreversible impact on human well-being (see Figure 3: Projected Impacts of Climate Change).

Figure 3: Projected Impacts of Climate Change



Source: Stern Review, 2006.

Holdren emphasized four approaches to mitigating climate change: changing the quality of human activities; altering emissions from natural resources; changing the rates at which substances are removed from the atmosphere; and changing characteristics of the environment to offset undesired influences on the climate. Using these approaches as a springboard, he listed three primary policy tools for addressing mitigation: legislate and enforce regulations; design and implement projects that address climate change; and increase government expenditures on research, development, and demonstrations of new projects to combat climate change.

Four factors influence the level of global carbon emissions, Holdren explained (see Figure 4: Technical Options). The first factor is population growth. Stemming population growth would be a win-win solution, he said. It would positively impact many global challenges such as hunger and poverty and could be achieved through improved education, access to health care, and reproductive rights for women, as well as increased job opportunities around the world. Other variables influencing GHG emissions are gross domestic product (GDP) per capita and the energy efficiency per capita. While lowering per capita GDP would be an unpopular move, increased energy efficiency "offers the largest, cheapest, fastest leverage," Holdren said, and can have a significant impact on emissions. The fourth factor affecting global carbon emissions is the carbon intensity of the energy supply. "Even a Prius still uses gasoline. Even a compact fluorescent bulb still uses electricity. We need to look at how much carbon dioxide goes into the atmosphere associated with producing that," he concluded.

Figure 4: Technical options for reducing fossil CO_2 emissions:

The emissions arise from a 4-fold product:

$$C = P \bullet \frac{GDP}{P} \bullet \frac{E}{GDP} \bullet \frac{C}{E}$$

Where C = carbon content of emitted CO_2 (kilograms),
The four contributing factors are

P = population, persons
GDP/P= economic activity per person, \$/person
E/GDP= energy intensity of economic activity, GJ/\$
C/E = carbon intensity of energy supply, kg/GJ

For example, in the year 2000, the world figures were:

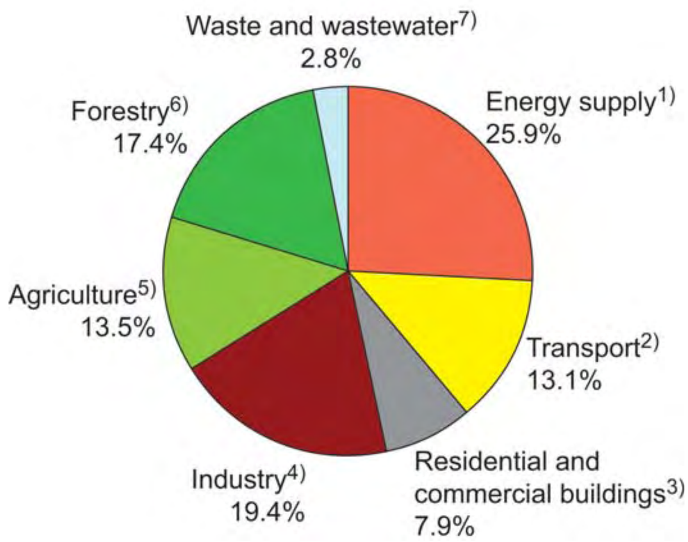
$$6.1 \times 10^9\, pers \cdot \frac{\$7400}{pers} \cdot \frac{0.01 GJ}{\$} \cdot \frac{14\, kgC}{GJ}$$

$$= 6.4 \times 10^{12}\, kgC = 6.4\ billion\ tonnes\ C$$

Source: John Holdren, Harvard University.

Holdren also reviewed other mitigation options, pointing out that CO_2 is not the only source of GHG emissions (see Figure 5: Mitigation Leverage). For instance, reductions in methane emissions (from, for instance, natural gas flaring) and the resulting soot would positively impact climate change. Another option is to remove GHGs from the atmosphere through increased tree coverage (e.g., afforestation, reforestation and avoiding deforestation). Ocean plants such as phytoplankton could "scrub" CO_2 from the atmosphere. Geoengineering ideas include increasing the earth's surface reflectivity, increasing the atmosphere's reflectivity, or placing reflecting materials in space (the latter may be cost prohibitive, with an estimated \$1400 trillion price tag).

Figure 5: Mitigation Leverage - Sources of GHG Emissions



Source: IPCC, 2007, "Mitigation of Climate Change," Working Group III Report, Figure 1.3b.

Holdren and other experts recommend a post-Kyoto regime that includes targets that stay 2-2.5°C below levels in 1750; performance metrics; carbon pricing; and carbon-revenue transfers from developed, high-emitting countries to underdeveloped, low-emitting countries. The authors of the UNSEG report further suggest that the United Nations use its resources and clout to promote an increase in education funding as well as public and private investments.

"Some of these measures involve win-win scenarios," Holdren concluded. For instance, increased energy efficiency and a slowdown of deforestation could lead to "sustainable well-being," an idea promoting environmental sustainability, development, and improved living conditions globally.

Rosina Bierbaum reviewed adaptation techniques and the impact of climate change in her presentation "Confronting Climate Change." Bierbaum cited evidence from the UNSEG report that changes already underway fit expected patterns. "Thirty percent more of the world is currently in drought than was in 1970, weather-related losses topped $375 billion in 2005, and increased flooding has occurred on every continent over the past 50 years," Bierbaum noted. The IPCC reported on more than 20,000 data sets which confirm that species are starting to shift to higher latitudes and altitudes (see Figure 6: Global Warming). "Evidence is mounting on every continent that change is underway. These changes will have profound impacts on our natural resources and our socioeconomic situations," she said.

Bierbaum further claimed that climate change also imperils the U.N. Millennium Development Goals (MDGs). These are a set of commitments aimed at reducing extreme poverty and improving health and educational opportunities worldwide (see Figure 7: The Millennium Development Goals). Climate change will make many of the MDGs harder to achieve, she argued, as agricultural productivity falls in developing countries, as disease vectors spread, and as heat waves increase.

Figure 6: Global Warming - Early Warning Signs

Source: Union of Concerned Scientists et al., http://www.climatehotmap.org.

Figure 7: U.N. Millennium Development Goals (MDG)

1. **Eradicate extreme poverty and hunger**
2. **Achieve universal primary education**
3. **Promote gender equality and empower women**
4. **Reduce child mortality**
5. **Improve maternal health**
6. **Combat HIV/AIDS, malaria, and other diseases**
7. **Ensure environmental sustainability**
8. **Develop a global partnership for development**

Source: United Nations, http://www.un.org/millenniumgoals/.

The impact of climate change on food supplies and water resources will negatively influence the ability to eradicate poverty and hunger, Bierbaum said. Furthermore, the possible heightened spread of disease that may accompany extreme climate events will also affect goals to reduce child mortality, improve maternal health and combat HIV and malaria. The World Health Organization (WHO) concluded that climate change has contributed to 150,000 deaths per year already and that it will likely contribute to the resurgence and redistribution of a number of infectious diseases such as West Nile virus, malaria and dengue fever. Another challenge will be populations in low-lying communities at risk of displacement by sea level rise. A sea level rise of 1-5 meters by the year 2100 would result in the displacement of 130-140 million people, according to studies cited in the UNSEG report.

“Climate change is degrading the progress [of the MDGs],” and “is changing the base line against which we are going to test things,” Bierbaum said. “If we continue with business-as-usual, it would lead to potentially serious and potentially catastrophic climate change that will threaten livelihoods and, we would argue, [the] development goals themselves. But if we muster the will and the technology and the finances to transform our energy systems and to improve the stewardship of our natural resources, we can achieve a sustainable future.”

Bierbaum also discussed measures necessary in the future to adapt to environmental changes already under way. She stressed the need to identify and understand vulnerable regions, expand adaptation research, and improve early warning systems. Like many mitigation strategies, adaptation strategies can also be "win-win." Many of the ideas proposed—such as increased surveillance for the spread of disease vectors, water conservation and management, and infrastructure fortification—can all be considered wise environmental management tools, regardless of climate change.

Bierbaum suggested that to plan for climate change consequences, institutional capacity should be harnessed and enhanced, then integrated into social networks. She encouraged the United Nations to start by identifying 15 vulnerable regions in the world every 2 years. In these regions, Rosina suggested that the United Nations conduct comprehensive assessments of the impacts of climate change, identify possible adaptation options, and propose new institutional arrangements to manage land and water resources in a world of changing climate. These regional assessments could serve as models or templates for other parts of the world. The UNSEG report noted that "the best way to address climate change impacts is by integrating adaptation measures into mainstream sustainable development and poverty reduction strategies."

"Humanity must act collectively and urgently to change the course through leadership of all levels of society," Bierbaum concluded.

IV. Policy Options for Reducing Carbon Emissions

Several options for reducing carbon emissions have been proposed in the United States. The discussions during the 2008 U.S. presidential campaign signaled a clear trend toward a more definitive position on climate change. This position was influenced by strong, preexisting state, regional, and local initiatives that range from binding emissions targets and developing renewable energy programs to engaging in collective action, like carbon-credit trading schemes.

California's independent stand on climate change, in particular, has stimulated debate about federal policies. According to state officials, California is the fifth-largest economy in the world; its transportation sector is the state's single largest source of GHG emissions; and, it is the ninth-largest emitter of GHGs per capita in the world. While California ranks low in CO_2 emissions per million tons of gross state product, it stands second, behind Texas, in total carbon emissions.

In fact, the 10 leading carbon-emitting U.S. states account for 50 percent of total U.S. carbon emissions, according to a study conducted by the Congressional Research Service.[5] The problems the state of California faces are similar to those developing elsewhere in the nation.

Initiatives in California and elsewhere have spurred a movement to link climate change programs along regional—and now transnational—lines. In 2003, the state of New York joined other mid-Atlantic and New England states to form the Regional Greenhouse Gas Initiative (RGGI). The RGGI introduced "a multi-state CO_2 emissions budget (cap) that will decrease gradually [by 2.5% annually] until it is 10 percent lower," than the original cap of the program effective date of January 1, 2009. RGGI aims to cap regional CO_2 emissions at 188 million tons across the ten member states.[6] Similarly, in 2003, a number of Western states formed a regional partnership, now called the Western Climate Initiative (WCI).[7] And in late 2007, governors from six Midwestern states and the Canadian province of Manitoba agreed to the Midwestern Greenhouse Gas Reduction Accord.[8]

Within the U.S. domestic policy community, two approaches to climate change are generally discussed: carbon taxes through higher federal fees on retail gasoline or a cap-and-trade regime that establishes a ceiling for carbon emissions and creates a system whereby industries would compete to buy permits to meet their carbon limits. These limits would become increasingly rigorous over time. Several bills proposing a cap-and-trade system have been introduced in the U.S. Congress. California has also proposed a statewide low-carbon fuel standard, which limits a fuel producer's carbon emissions per unit of output. California low-emission vehicle (LEV) regulations further enforce reductions in passenger vehicle, light-duty trucks, and medium-duty vehicle exhaust emissions, and also include provisions for the introduction of zero-emission vehicles to the CA fleets.[9] A federal low-carbon fuel standard has also been proposed on Capital Hill.

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[5] Jonathan L. Ramseur, "State Greenhouse Gas Emissions: Comparison and Analysis," *Congressional Research Service*, December 5, 2007, p. 2 (summary), http://www.energywashington.com/secure/data_extra/dir_07/ew2007_3746.pdf.
[6] Regional Greenhouse Initiative, http://www.rggi.org.
[7] Western Climate Initiative, http://www.westernclimateinitiative.org.
[8] Midwestern Governors Association, http://www.midwesterngovernors.org/govenergynov.htm.
[9] California Environmental Protection Agency Air Resources Board, http://www.arb.ca.gov/homepage.htm.

A discussion of these various options was the subject of a panel consisting of Daniel Sperling, director of the Institute of Transportation Studies at the University of California, Davis; Milo Sjardin, head of New Carbon Finance, North America; and, Gilbert E. Metcalf, professor of economics at Tufts University.

In his presentation, "The California Model for Combating Climate Change," Sperling remarked that California is well-positioned to lead climate policy and acts as a "laboratory for others to learn from." California represents a large, relatively isolated market with innovative consumers and industry; bipartisan support existed there for climate legislation with virtually no major local coal or automotive industries to hinder the political process, Sperling said.

Sperling highlighted two California legislative initiatives: the Pavley Law (Assembly Bill 1493) and the California Global Warming Solutions Act of 2006 (Assembly Bill 32). The Pavley Law, enacted in 2002, requires the California Air Resources Board (CARB) to establish more stringent standards for vehicle GHG emissions starting with the 2009 model year. Under the Pavley Law, cars and trucks will be required to emit 30 percent fewer GHGs by 2016. To enforce the Pavley Law, CARB first had to receive a waiver from the U.S. Environmental Protection Agency (EPA). The waiver, under Section 209(b) of the federal Clean Air Act (CAA), would permit the state to set vehicle emission standards that exceed federal standards.[10]

The EPA denied California's waiver request on December 19, 2007, stating that because "greenhouse gases are fundamentally global in nature," California and other states with similar requests did not show the "compelling and extraordinary conditions" necessary to exceed federal emissions standards.[11] The EPA added that the federal Energy Independence and Security Act of 2007 (HR 6), signed into law earlier that day, offered a more comprehensive approach to GHG

[10] In order to receive a waiver, a state must meet certain criteria required by Section 209(b) of the CAA, and the criteria must be reviewed by the EPA in public hearing prior to an EPA ruling on the issue.
[11] U.S. Environmental Protection Agency, December 19, 2007, "America Receives a National Solution for Vehicle Greenhouse Gas Emissions," http://yosemite.epa.gov/opa/admpress.nsf/eebfaebc1afd883d85257355005afd19/41b4663d8d3807c5852573b6008141e5!OpenDocument/.

reduction. The new regulation increased vehicle fuel economy as well as the amount of renewable fuel required in the gasoline fuel pool.[12]

In response to the EPA's waiver-request denial, California governor Arnold Schwarzenegger filed suit against the EPA on January 2, 2008. The state was joined by "New York, New Jersey, Connecticut, Pennsylvania and 11 other states as well as five environmental organizations, including the Natural Resources Defense Council."[13] Sperling remarked that before the waiver rejection, other states adopted the Pavley standard, which could have "covered at least half of all vehicles in the United States."[14] He predicted the next administration will likely approve the waiver. It is also possible that the U.S. Congress, now with a stronger Democratic majority, will change the law to allow California and other states to proceed, Sperling said.

California took another step to reduce GHG emissions on September 27, 2006, when Schwarzenegger signed the California Global Warming Solutions Act. Also known as Assembly Bill 32 (AB 32), the act requires the CARB to implement a Scoping Plan, the state's strategies for reducing GHG emissions, by 2012. AB 32 calls for total California GHG emissions to be reduced to 1990 levels by 2020. This roughly represents a 28 percent reduction from business-as-usual levels. Separately, the governor issued an executive order setting a GHG reduction target of 80 percent below 1990 levels by 2050.[15]

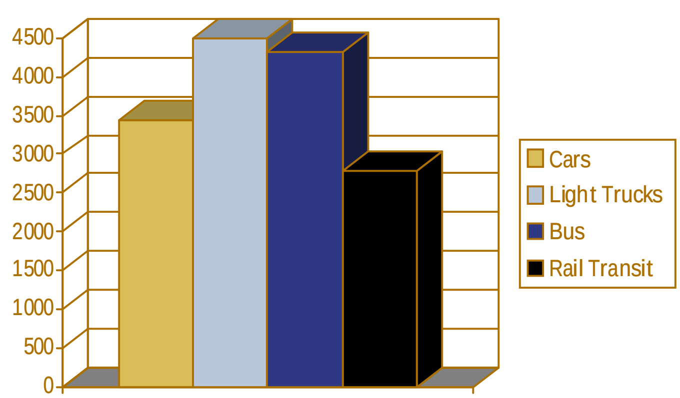
Under the provisions of AB 32, the CARB has approved a list of early action measures to be implemented by January 1, 2010. The measures include Low-Carbon Fuel Standards (LCFS), which limit a fuel producer's carbon emissions per unit of output. Sperling believed that low-carbon fuel standards represent an important strategy for reducing GHG emissions. They create a durable framework for orchestrating near and long-term transitions to low-carbon alternative fuels and stimulate technological innovation, he said. The LCFS will use life cycle analysis and are preferable for quantifying net emissions, Sperling added, because they do not force the

[12] HR 6 requires that all cars and trucks sold in the United States meet a 35 mile-per-gallon fleet-wide standard by the year 2020.
[13] Office of the Governor, "Governor Schwarzenegger Announces EPA Suit Filed to Reverse Waiver Denial," news release, January 2, 2008, http://www.gov.ca.gov/press-release/8400/ and New York Times, "California Sues E.P.A. Over Denial of Waiver," January 3, 2008, http://www.nytimes.com/2008/01/03/us/03suit.html.
[14] New York Times, "E.P.A. Says 17 States Can't Set Emission Rules," December 20, 2007.
[15] Executive Order S-3-05. Office of the Governor of California, http://gov.ca.gov/index.php.

government to pick winners or losers. They also provide consistency and compatibility between states and countries.

Sperling noted that the Pavley Law and current Corporate Average Fuel Economy (CAFE) standards are nevertheless inadequate, voicing concerns that these regulations ignore the importance of reducing vehicle miles traveled (VMT) by average drivers. They provide no major incentives for consumers to reduce fuel use, and they fail to recognize the large start-up cost barriers for very low-carbon vehicles. Moreover, the regulations do nothing to create an alternative fuel distribution system. Sperling also commented that expansion of public transit options is not enough alone to reduce oil use or GHG emissions (on average). In his opinion, transit reform coupled with policies and strategies that reduce VMT and support low-carbon technologies and distribution networks are required to achieve meaningful reductions. As an example, he stated that the energy intensity of buses is about the same as cars in some cases (see Figure 8: Average Energy Intensity of Vehicles in the United States).

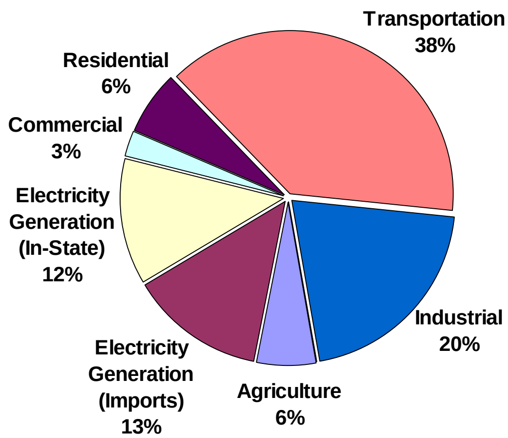
Figure 8: Average Energy Intensity of Vehicles in the United States (*Btu per Passenger Mile)*



Sources: Stacy Davis and Susan Diegel, U.S. Department of Energy, and Oak Ridge National Laboratory, Transportation Energy Data Book, Edition 26, 2007.
Note: Actual intensities vary dramatically across time of day, routes, and regions (and by trip purpose for cars). According to the U.S. Energy Information Administration (EIA), a British Thermal Unit (Btu) is defined as "the quantity of heat required to raise the temperature of 1 pound of liquid water by 1°F at the temperature at which water has its greatest density (approximately 39°F)."

Since transportation contributes to 38 percent of GHG emissions in California (see Figure 9: California GHG Emissions by Sector), Sperling recommended that state legislators focus on the transport industry and direct efforts to reduce emissions through more efficient vehicles, lower-carbon fuels, and fewer VMT. Other fuel-related strategies to reduce oil use include subsidies and mandates, "new" renewable fuel standards, carbon taxes, and cap-and-trade market development. However, Sperling emphasized that taxes and caps are not enough alone. He proposed carbon budgets for cities and counties, which make the entities accountable, giving them the flexibility to respond to inputs specific to their experience and providing incentives for substantial improvements and changes.

Figure 9: California GHG Emissions by Sector



Source: California Air Resources Board, 2007.

Sperling closed with a list of principles to help guide climate change policy: do not pick winners; push responsibility downstream as much as possible (to cities and companies, for instance); create choices that will open up policy and politics; create a durable policy framework for carbon emission; target market failures and start-up barriers to improve market access and increase incentives; reform the transport sector; and encourage bottom-up and top-down policy experimentation (within overlapping federal-state-local responsibilities).

Milo Sjardin, head of New Carbon Finance, North America, laid out the case for a market-based cap-and-trade system to reduce carbon emissions. Basing his argument on the European experience, he called cap-and-trade "the preferred policy measure to ensure emissions reductions" globally. The European Union (E.U.) learned from early failures, said Sjardin, who believed its emission trading scheme (ETS) "has so far been very successful in stimulating the transition to a carbon-constrained economy."

Adopted by the E.U. Environment Council on October 13, 2003, the ETS has been in effect since January 2005.[16] The ETS established a cap-and-trade system for E.U. member states and is currently the largest trading scheme in operation, covering 46 percent of CO_2 emissions in the E.U.. The value of global emissions trading has increased from $11 billion in 2005 to an estimated $64 billion in 2007. All 27 E.U. member states are involved in the ETS. ETS targets are legally binding and carry a fine of 100 euros/ton of carbon emitted in excess of the allowance. The ETS has been a driving force for investment and technology transfer in emerging economies, Sjardin said, and emissions reductions from 3,103 projects are expected to exceed 2.6 billion tons by 2012.

System compliance is achieved via allowances and credit trades through two project-based mechanisms: Joint Implementation (JI) and the Clean Development Mechanism (CDM). Both mechanisms are outlined in the Kyoto Protocol and may be used by Annex I Parties to fulfill their Kyoto targets.[17] JI and CDM credits can also be converted to ETS allowances by companies and governments.[18]

The key principles of the ETS are to provide certainty by establishing an emissions reduction target and to ensure that emissions reductions occur where the cost is lowest, the latter being determined by the market. Sjardin described the ETS in three phases: the Learning Phase (2005–2007), the Kyoto Commitment Period (2008–2012), and the Post-Kyoto Period (2012–2020).

At the end of the Learning Phase (Phase I), the value of the carbon credit dropped to zero, which Sjardin believed was due to three problems with the scheme (see Figure 10: Historic E.U. ETS

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[16] Climate Action Network Europe, http://www.climnet.org/euenergy/ET.html.
[17] United Nations Framework Convention on Climate Change, *Joint Implementation,* http://unfccc.int/kyoto_protocol/mechanisms/joint_implementation/items/1674.php.
[18] "The European Emissions Trading Scheme and the Future of Kyoto" (Presented at the Yale Center for the Study of Globalization, October 21-22, 2005), http://www.ycsg.yale.edu/climate/forms/Klepper.pdf.

Price Development). First, credit allocations were based on inaccurate or unavailable emissions data. Therefore, credits were over-allocated as governments and industries overestimated emissions. In addition, allocations were based on future emissions projections and did not reflect historical trends. Finally, credits could not be banked from Phase I to the Kyoto Commitment Period (Phase II). This was done intentionally to ensure that no emissions reductions were carried over from Phase I to Phase II. However, Sjardin said that "it was a good thing that the price development dropped to zero, because the other alternative was a skyrocketing of prices, which would have been politically unacceptable. The first phase was also designed as a learning phase in order to make necessary adjustments for the second and third phases."

Sjardin reviewed five lessons learned from experiences during Phase I of the E.U. ETS. First, an over-allocation of permits (partly due to incorrect emissions data) hindered the European system. Thus, it is important that the number of permits issued is limited to promote adequate carbon pricing in the marketplace and restrict carbon emissions. Second, increased auctioning activity can prevent distortions created by free allocation, reduce windfall profits, and stimulate low-carbon investment.[19] Third, banking and borrowing without limits is essential to prevent prices from going to zero, and to support stable prices as well as long-term predictability. Fourth, lowering import levels for emissions reductions from abroad is desirable to keep the focus on domestic emissions reductions. Finally, Sjardin recommended that E.U.-wide cap-and-allocation methods be harmonized to eliminate variations in stringency and coverage between member states.

From an investment standpoint, Phase II prices have stayed within the 15–25 euros/ton of carbon range since early 2005. Sjardin predicted that during Phase II, the carbon price will likely remain at 25 euros/ton of carbon. Market behavior plays a large role in cap-and-trade programs, Sjardin remarked. In the ETS experience, the demand for allowances has been constant, whereas the supply of allowances has grown over time (see Figure 11: Market Behavior). He attributed this to smaller industrial facilities that retained allowances for possible future use—resulting in a deficit of allowances in the marketplace even though there was a small supply in the beginning.

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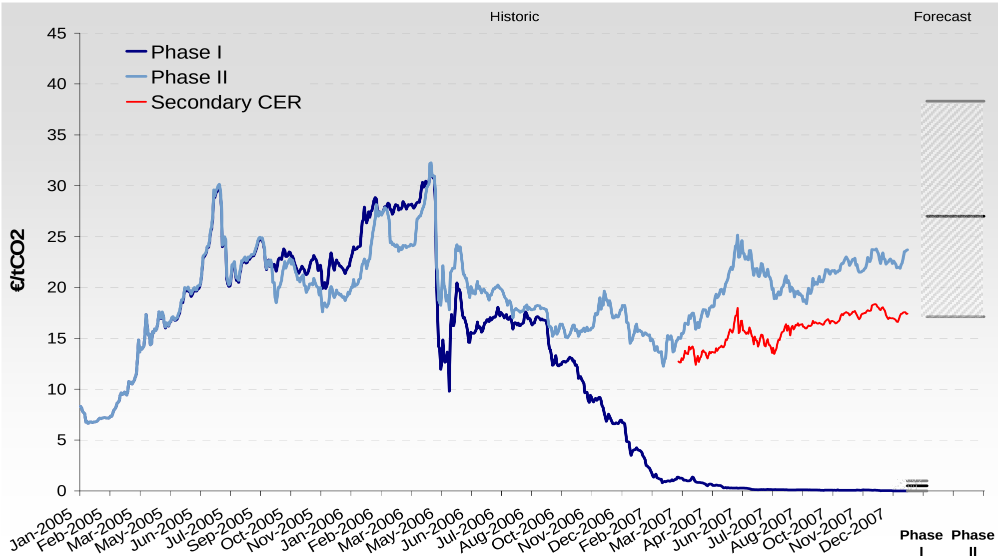
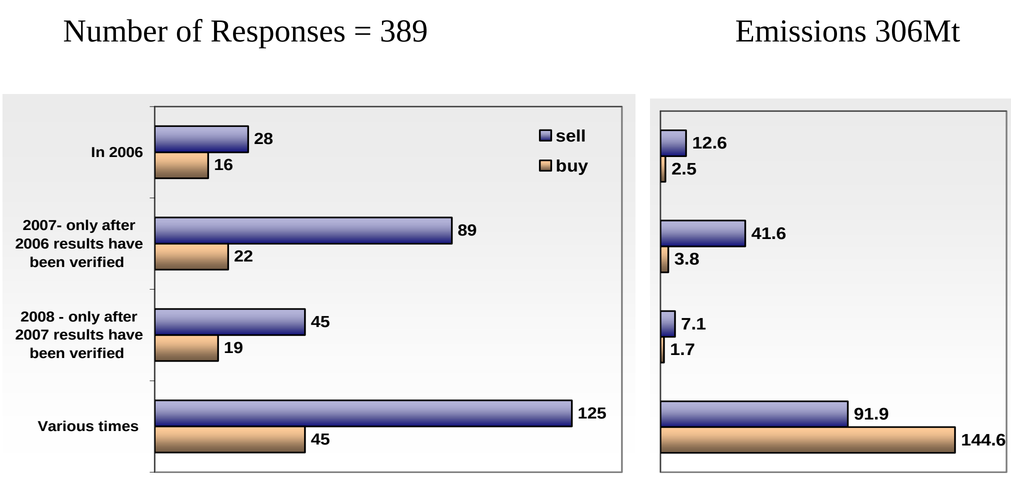
[19] Cameron Hepburn et al., "Auctioning of E.U. ETS Phase II Allowances: How and Why?" http://www.electricitypolicy.org.uk/pubs/tsec/hepburn.pdf.

Figure 10: Historic E.U. ETS Price Development



Source: New Carbon Finance, ECX, Reuters.
Note: Increased demand from utilities, higher gas prices (until July 2005); verified emissions data released June 2006; drop-off in electricity demand due to mild weather, a decrease in fuel prices, and surplus coming on to market (between November 2006 and March 2007); market confidence in Phase II increases as stricter National Allocation Plans (NAPs) are made (starting around March-April 2007).

Figure 11: Market Behavior of E.U. ETS Plays a Large Role



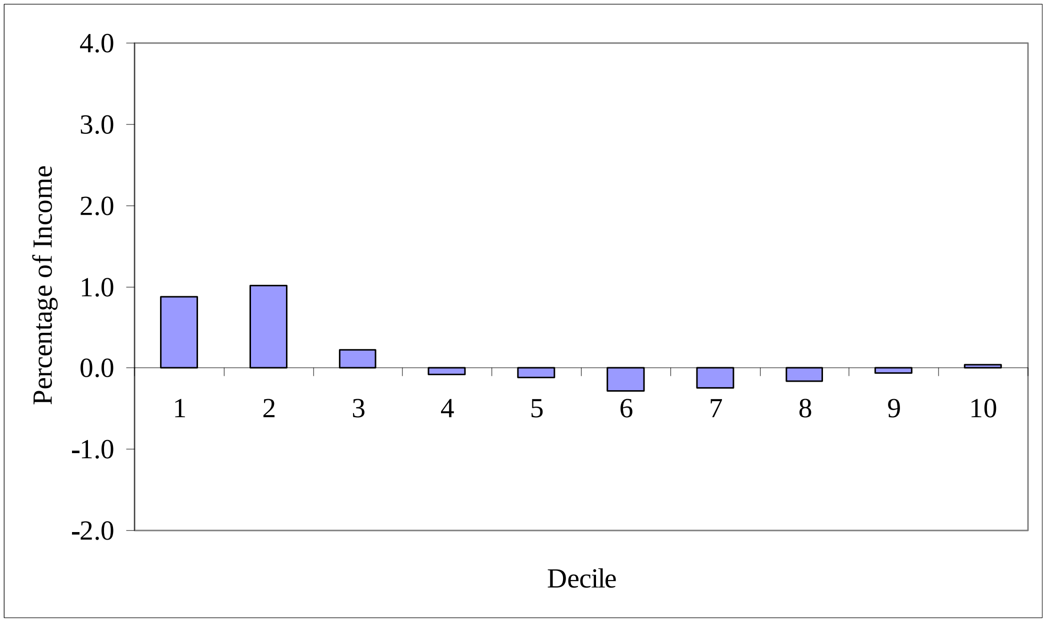
Source: New Carbon Finance Survey of all E.U. ETS participants (585 responses total).
Note: Phase I has shown that utilities are constant buyers whereas industrials hold allowances due to uncertainties of future needs; this behavior is likely to be repeated, albeit less extreme.

Sjardin noted that despite its initial problems, the E.U. ETS provides a successful paradigm for cap-and-trade. The ETS offers transparent carbon prices, which Sjardin predicted will be at least 50 euros/ton of carbon between 2012 and 2020. The E.U. ETS also establishes an efficient market with numerous participants and an increasing variety of related financial products in active trading. Furthermore, cap-and-trade seems to be the globally-preferred policy tool to ensure emission reductions, Sjardin concluded. By creating an overall successful trading scheme, it provides a visible, transparent carbon market and creates certainty for investors.

Speaking on the same panel as Sjardin, Gilbert E. Metcalf, professor of economics at Tufts University, offered an alternative view, asserting that a carbon tax would be more effective than a cap-and-trade system. He acknowledged that while the tax approach is not politically expedient in the United States, he believed public opinion is shifting. He noted that a carbon tax was too difficult to pass in the E.U. because it was a fiscal, as opposed to regulatory, measure and would have required unanimity among all member countries to receive approval—a difficult feat to achieve.

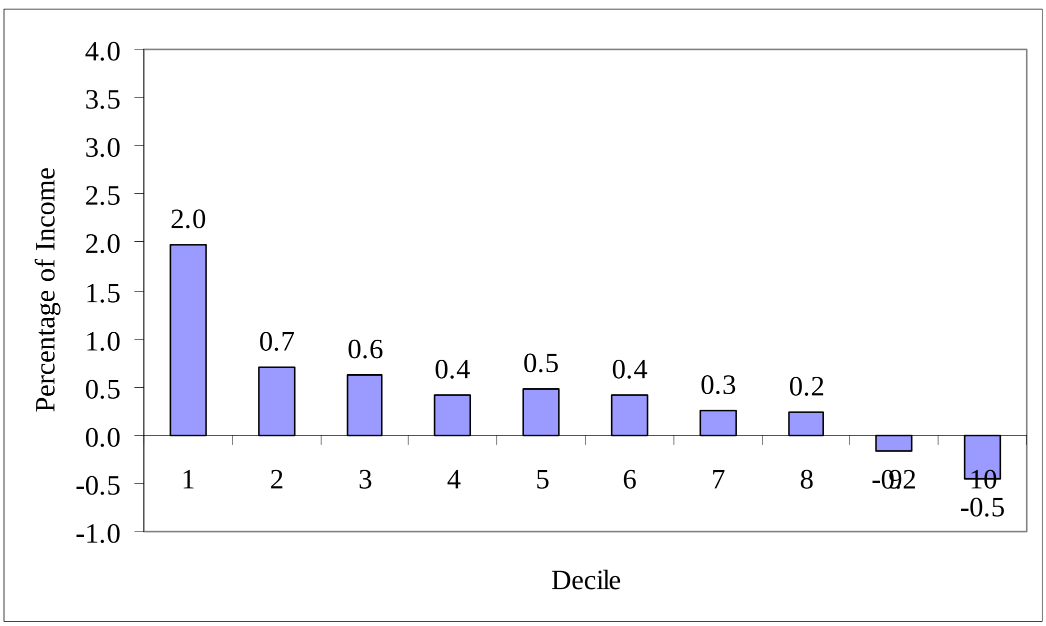
Metcalf thought that although any form of carbon pricing is regressive, such effects can be undone in the United States through a well-designed rebate plan for carbon revenue (see Figure 12: Net Burden and Figure 13: Distributional Impact). Nevertheless, he acknowledged the difficulties involved in setting a carbon tax optimally at the present time. “There’s a classic textbook solution, which is that we want to put a price on greenhouse gas emissions equal to their marginal damages,” he said, adding that measuring marginal damages is difficult because there is a wide range of estimates that run from zero to over $100/ton CO_2. Given lags in effects, “we cannot wait to act until we know marginal damage to set carbon price precisely,” Metcalf summarized.

Figure 12: Net Burden of Carbon Tax



Source: Gilbert E. Metcalf, Tufts University.

Figure 13: Distributional Impact of Grandfathering on Income Levels



Source: Metcalf.
Note: Grandfathering precludes the opportunity for distributional offsets.

Metcalf described several carbon tax bills that have been proposed in the U.S. Congress. One proposal, drafted by U.S. Representative John Dingell (D-MI), called for a $50 per ton tax on carbon ($13.36 on CO_2) and a 50 cents per gallon gasoline tax, with revenue linked to various spending programs and the U.S. Highway Trust Fund, which is currently funded by existing federal gasoline taxes. Another bill, introduced by U.S. Representative Pete Stark (D-CA), proposed a $10 per ton carbon tax that would rise annually by $10 until emissions fall below 80 percent of 1990 levels. Metcalf stated that the latter bill was not sufficiently stringent to actually reach that 80 percent target in the foreseeable future. A third bill, introduced by U.S. Representative John Larson (D-CT), proposed a $15 per ton tax on CO_2, growing at 10 percent a year in real terms for fossil fuel CO_2 emissions. This bill provided income tax relief for low-income Americans to make the measure economically neutral.

Metcalf proposed that a primary concern of any energy tax, including the pricing of CO_2, is the distribution effect. Higher prices for energy, which are likely to result from carbon pricing, will disproportionately impact low-income households. Metcalf noted that carbon taxes have been shown to be distinctly regressive, with half of the tax burden passed on through non-energy products. Poorer households will pay an estimated 3 percent of income to cover higher costs compared to the 1 percent wealthier households will pay, if no rebate is issued to offset the tax.

Metcalf further stated that a cap-and-trade system that issues permits for free "simply leads to higher returns to shareholders in the energy sector, and owners of shares tend to be wealthier than typical households in the U.S. economy … so the impact of complete grandfathering is distinctly regressive." According to Metcalf, the top 20 percent of the income distribution is actually "made better off by this policy [free permits under cap-and-trade], which is being paid for in higher prices by the lowest-income families in the distribution curve. So I think there is a real distributional cost to grandfathering."

Economic modeling consistently shows that a tax, which fixes price, not quantity, is a more efficient method to reduce GHG emissions than a cap-and-trade system, which fixes quantity but not price, Metcalf remarked. Both systems generate a revenue stream, but revenues from a cap-and-trade system are only included in the federal budget if the permits are auctioned. If permits are given free of charge to large emitters, as has been proposed under some systems, they represent a hidden transfer of revenue. “As a fiscal policy process issue, I think it is valuable to include the revenue in the budget process explicitly; and with cap-and-trade, that only happens if all permits are auctioned,” he noted. “This is part of the appeal of cap-and-trade that we obscure the transfers that are going on but it also has some peculiar outcomes.” The money at stake is quite large, perhaps ten times larger than the sums generated by acid rain SO_2 permits. At a $15 per ton CO_2 price, revenues could reach $80 billion a year, according to Metcalf. Thus, since permits are valuable assets, emphasis should be placed on compensating affected parties, not rewarding regulated sectors. A carbon tax swap is a better way to address affected parties than free permits under a cap-and-trade system, according to Metcalf. “I just think that giving $80 billion annually to special interest groups to purchase their support, quite bluntly, is bad public policy,” Metcalf said, adding that full auctioning of permits should be a guiding principal for any cap-and-trade system.

Metcalf also discussed that price volatility in a cap-and-trade system can make investment planning “quite difficult” for firms, observing that downside risk is always a concern with a cap-and-trade system. “That’s a problem if you are thinking about making expensive investments in new capital that reduces carbon intensity.” Metcalf suggested the possibility of a hybrid system that mixes attributes of both. “We can really overstate the differences between the two systems, in part, because there are hybrid schemes that mix attributes of both approaches, whether it’s a safety valve [where government will issue more emissions credits if their price exceeds a certain level, effectively setting a ceiling price], or including a cap-and-trade system with a carbon fee.”

One goal of carbon tax or permit pricing systems is to spur innovation. But Metcalf expressed concern that there is no guarantee that carbon prices will rise high enough in a cap-and-trade system to induce expensive capital investments in alternative energy. Metcalf criticized California’s LCFS, which shifts the burden of carbon emissions reductions onto automobile and fuel producers. He said that the marginal costs for carbon emission reductions exceed $1,000 per ton. “We want to be careful about forcing particular sectors to be making these cuts that will be expensive. We want to make them [the cuts] in the cheapest way possible.” To do this, Metcalf says it is important to cover as much of the emissions as possible by implementing comprehensive programs that cover all sectors. Metcalf recommended carbon taxes or prices be applied “upstream”—at the coal mine, refinery gate or electric utilities—as opposed to “downstream” at the point of fuel use. He also said it was important to regulate other gases besides CO_2.

Metcalf called for lawmakers to consider a carbon tax swap system similar to the one proposed in the Larson bill. This system would include a tax on emissions that would increase over time, a refundable tax credit for sequestration activities, and a broader tax adjustment for fossil fuels. The carbon tax swap would also include an environmental earned income tax credit on personal income tax, similar to payroll taxes on initial earnings, but with a limit. The credit would offset payroll taxes for a certain level of earnings per worker. Metcalf concluded that either a cap-and-trade or a carbon tax system could be successful as long as it takes into account distributional issues. “If we go with cap-and-trade, I would be perfectly happy. I would prefer a carbon tax, but I think that any carbon pricing is desirable,” he said.

V. Climate Change Policy: Economic Issues

The economics of climate change policy were addressed by John Weyant, professor of management science and engineering and director of the Energy Modeling Forum at Stanford University; Dimitri Zenghelis, head of the Stern Review Team in the Office of Climate Change at the U.K. HM Treasury; Scott Nyquist, a director at McKinsey & Company; Peter Hartley, Baker Institute Rice Scholar and the George and Cynthia Mitchell Chair and professor of economics at Rice University; and Mort Webster, assistant professor of public policy at the Massachusetts Institute of Technology (MIT).

In his presentation, “The Economic Costs of Climate Change,” Weyant discussed global warming as a risk-assessment problem. Contrary to proponents of an all-or-nothing approach, Weyant argued that acting on the best, currently available information was the best response to climate change. Accuracy will be limited since, in Weyant’s view, scenarios a decade from now cannot be accurately gauged or predicted due to the human ability to adapt to change by creating new solutions and technologies over time. Weyant emphasized that it would be a mistake to wait for perfect information before taking action. "We can find general trends in predictions and from these create general policies that we can adapt over time as we learn more," he explained. "As we learn more, we have to be willing to eliminate ineffective policies."

According to Weyant, flexible policy architecture allows for continual redirection, which lets "a thousand flowers bloom and different regions do what they can do easily, politically, resource-wise and economy-wise, because everybody has a different resource base, a different economic structure and a different set of policies."

However, Weyant believed that flexible policy will not be enough to effect change. He proposed that policy must be drafted to encourage technology development, and that policy uncertainty and unstable price signals over time are significant constraints on innovation.

Weyant noted that, despite technological advances, mitigation costs are very uncertain. He warned that the costs depend on future fuel prices, economic growth, and the manner in which policies are implemented. The extent and level of international cooperation will also impact costs. Weyant said studies have shown that stabilization could cost anywhere between 0.1 percent (with an effective international approach) and 10 percent (without a concise, organized international effort) of global GDP per year.

Weyant concluded that general policy principles can be established to minimize costs associated with mitigation and adaptation as well as to determine the portion of the resource base to devote to climate change rather than to other global issues. A flexible policy will permit institutions and technologies to collaborate more cost-effectively and efficiently as new information is gained.

Regardless of the paths chosen to reduce the impact of climate change, many nations are electing to act on the IPCC conclusions that anthropogenic GHG emissions (those emissions resulting from human activity) are accelerating the rate of climate change. Economists are attempting to model projected climate change, from the best to worst case scenarios, to determine the economic costs and benefits of policies and actions designed to reduce anthropogenic emissions.

In his presentation on "The Economic Impact of Climate Change: The Stern Review," Dimitri Zenghelis, head of the Stern Review Team, reviewed the report and discussed the economic and policy implications of a carbon constrained world.

One of the most discussed economic reports on climate change, the *Stern Review*, was released in December 2006 by Sir Nicholas Stern, former head of the Government Economic Service and adviser to the U.K. government.[20] The review assessed the economics of climate change for the Treasury of the United Kingdom and addressed the long-term economic impacts of climate change and various mitigation and adaptation policies.

The report begins with the assumption that "the scientific evidence is now overwhelming: climate change presents very serious global risks, and it demands an urgent global response."[21] It ultimately concludes that "the benefits of strong, early action considerably outweigh the costs," and that ignoring climate change will potentially create massive economic disruptions in the future.

The *Stern Review*'s conclusions about the expected impact of climate change are conservative compared to other studies, Zenghelis said. The review assumes that it will only be possible to stabilize CO_2 emissions at concentrations of 550 ppm, which would probably still result in a 2-3°C rise in the earth's temperature by 2050 (using the IPCC range). As a result, severe water shortages and malnutrition could affect up to a billion people.

Given the high level of uncertainty regarding impacts of climate change, the *Stern Review* presents a range of possible scenarios, rather than a single estimate, according to Zenghelis. Uncertainty should be expected, he emphasized, because it is not possible to anticipate all degrees of impacts a century from now. In contrast to several other studies, which focus only on quantifiable variables, the *Stern Review* attempted to present a more complete assessment that takes into account hard-to-quantify impacts, such as changes in human health and other social externalities, he added. But the report did not calculate the cost of other, more difficult to assess,

[20] HM Treasury, *Stern Review: The Economics of Climate Change, 2006,* http://www.hm-treasury.gov.uk/stern_review_report.htm.
[21] *Stern Review,* Executive Summary, p 1.

socially contingent factors such as war or migration, leading Zenghelis to conclude that the review's estimates are actually "conservative."

The most frequently discussed method to mitigate the effects of climate change is reducing anthropogenic emissions, particularly CO_2 emissions. The *Stern Review* estimates that costs could be as little as 1 percent of GDP worldwide if immediate action were taken, but given probable delays in many countries, the total cost will likely be greater than 1 percent and costs will not be borne equally by the populace.

Zenghelis noted that some countries will inevitably pay more than 1 percent of GDP to reduce their GHG emissions. The total cost per country will depend on each country's fossil fuel intensity and its ability to substitute different sources of energy. But Zenghelis conceded that top-down economic models require "a lot of behavioral assumptions "and "they cannot represent all of the substitution opportunities available in an economy…which actually may tend to overstate the costs."

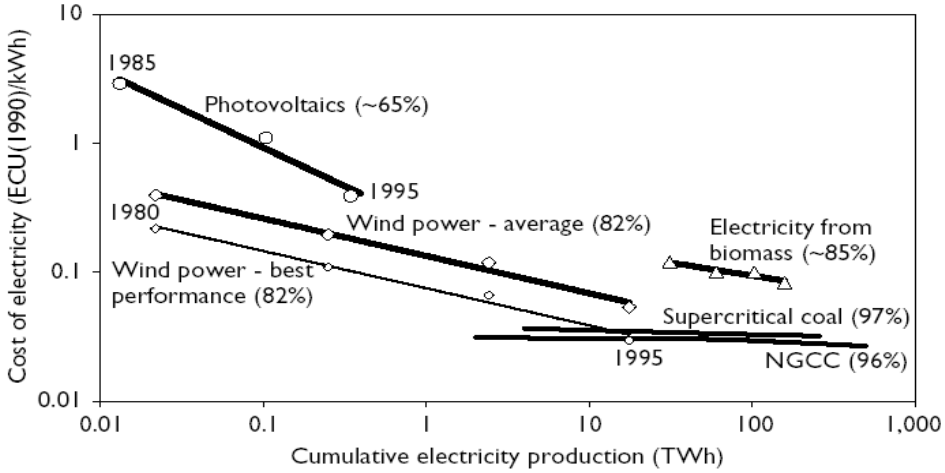
The *Stern Review* model discounts future values, applying the law of diminishing marginal utility. In other words, the value of a dollar to a poor person is counted as greater than the value of a dollar to a wealthy person. The *Stern Review* assumes that changes in societal wealth make the society risk averse, despite any relative gains (of a similar amount to wealth lost) that may accrue.[22]

Zenghelis added that since countries are likely to reduce emissions at different rates of speed, carbon leakage will result. Carbon leakage occurs when emission-intense businesses relocate to countries where regulations have not yet been implemented, essentially causing a shift, rather than a reduction, of carbon.

[22] In this scenario, discounting of future values is actually very small since weight is given to large negative impacts even when they have a low probability of occurring; combined with egalitarianism, this results in even lower discount rates, as the impacts of climate change could result in decreases in human wealth. Future values are discounted for the risk of non-existence; however, current values are not discounted, because of increased concern for the present over the future.

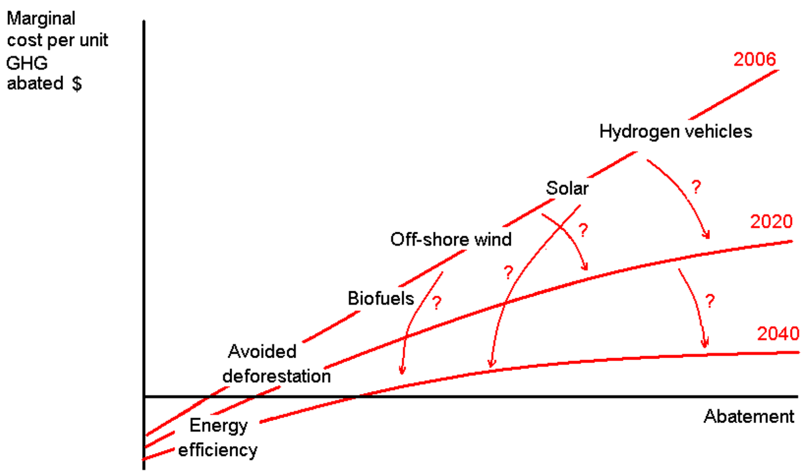
Zenghelis believed that to reduce GHG emissions, countries will have to use a combination of costly big-ticket schemes, such as solar electricity generation and carbon sequestration (see Figure 14: Cost and Figure 15: Marginal Abatement), and a large number of smaller, relatively cost-free adaptations, such as consumer conservation. However, changes in consumer behavior depend on an increased awareness of the cost-savings an energy-efficient lifestyle can bring.

Figure 14: Cost of Various Electricity-Producing Technologies



Source: Stern Review, 2006.
Note: Some arguments for differential policies given the nature of technologies and distance from markets.

Figure 15: Marginal Abatement Option Cost Curve



Source: Stern Review, 2006.

Zenghelis emphasized that the United States must show leadership on climate change by gaining the cooperation of the international community (see Figure 16: Key Principles). If the United States reduces emissions, but does not inspire the rest of the world to action, then its efforts are wasted, Zenghelis concluded. Therefore, a shared understanding of responsible behavior must arise from an international consensus on the importance of climate change and its possible distributional impact.

Figure 16: Key Principles of International Action

Effective action requires:

- Long-term quantity goals to limit risk; short-term flexibility to limit costs
- A broadly comparable global price for carbon
- Cooperation to bring forward technology
- Moving beyond sticks and carrots
- Equitable distribution of effort
- Transparency and mutual understanding of actions and policies

Source: Stern Review, 2006.

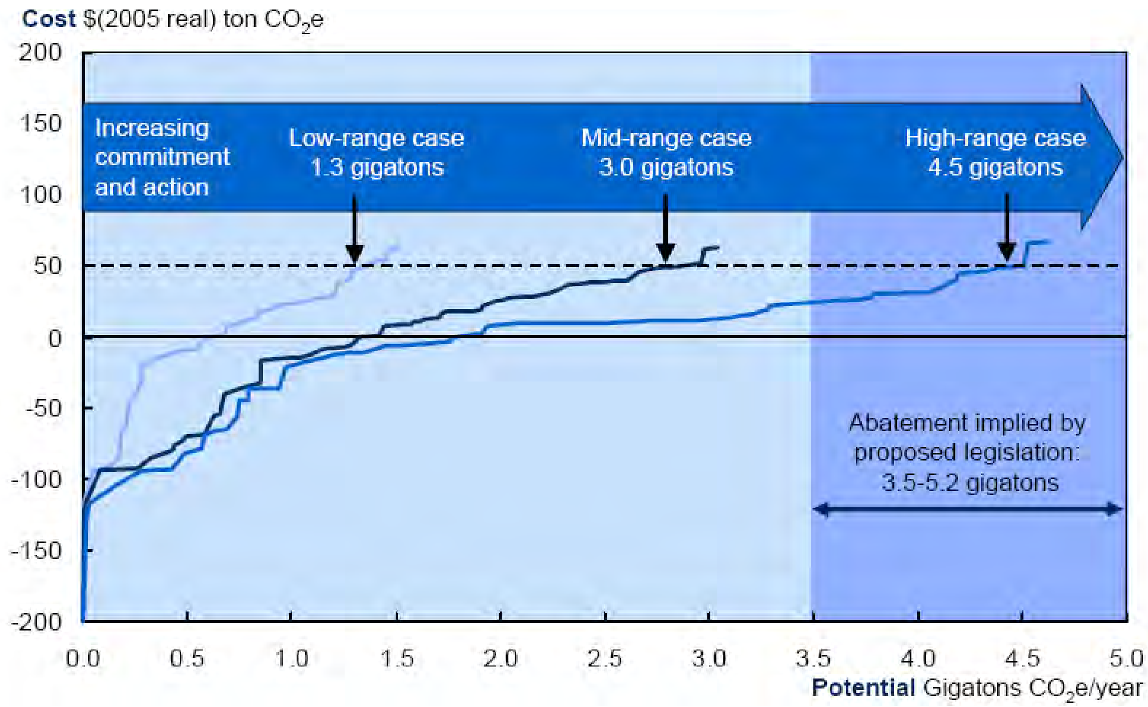
Scott Nyquist, a director at McKinsey & Company, presented a new study by McKinsey analyzing the costs of reducing GHG emissions in the United States. The report, entitled *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?,*[23] found that the United States could reduce GHG emissions by 3-4.5 gigatons of CO_2 emitted by 2030 "using tested approaches and high-potential emerging technologies." (See Figure 17: CO_2 Reduction Potential). "These reductions would involve pursuing a wide array of abatement options with marginal costs less than $50 per ton, with the average net cost to the economy being far lower if the nation can capture sizable gains from energy efficiency," Nyquist stated.

The McKinsey report authors based their analysis on the science of climate change, which suggests that in order to stabilize the atmosphere, worldwide carbon emissions must be reduced by 90 percent in the long-term. The business-as-usual approach to emissions results in 85 gigatons of CO_2 emitted ($GtCO_2e$) globally by 2050—up from just 40 $GtCO_2e$ in 2002. A global

[23] McKinsey & Company, *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?,* U.S. Greenhouse Gas Abatement Mapping Initiative, December 2007, http://www.mckinsey.com/clientservice/ccsi/greenhousegas.asp.

mapping of abatement opportunities showed that 26 to 27 $GtCO_2e$ could be abated by 2030 at less than 40 euros per ton of CO_2 emitted (see Figure 18: McKinsey's Global Mapping).

Figure 17: CO_2 Reduction Potential



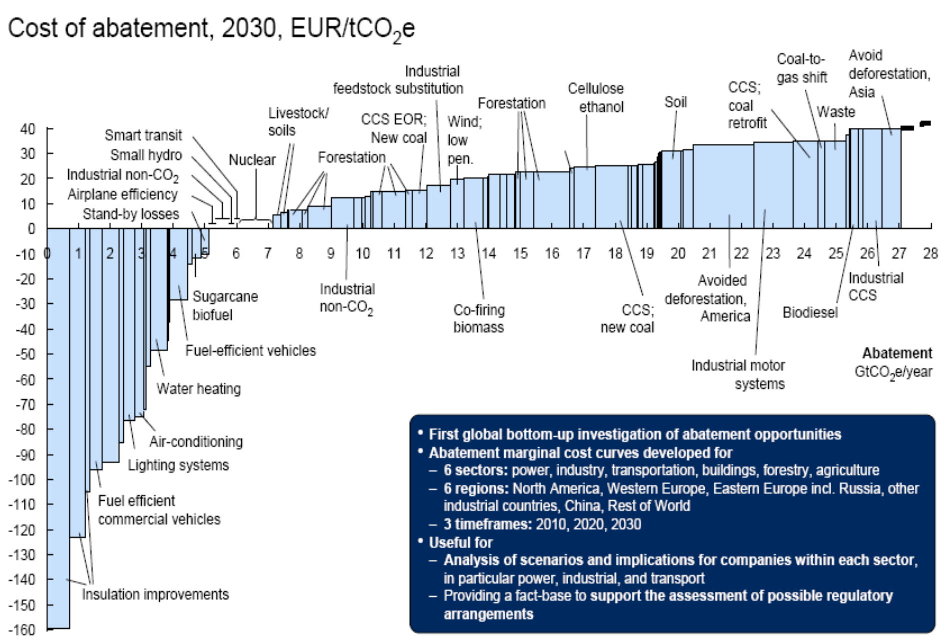
Source: McKinsey & Company
Note: The chart is based on bills introduced in the U.S. Congress that address climate change and/or GHG emissions on an economy-wide basis and have quantifiable targets; targets are calculated off the 2030 U.S. GHG emissions of 9.7 $GtCO_2e$ per year (reference case).

The report identified 250 opportunities for emissions reductions in seven sectors of the U.S. economy that met the following criteria: the opportunities would cost less than $50 per ton of carbon reduced; the technology and approaches must have predictable costs and development paths; full life cycle and maintenance costs must be considered; and constant consumer lifestyles must be assumed (so that reductions would be due to higher efficiency or lower emission fuels with no decline in quality of life). Based on these criteria and results, McKinsey determined that the United States has more opportunities to reduce emissions through efficiency gains than the rest of the world, largely due to inefficient appliances currently in use in the country (see Figure 18: McKinsey's Global Mapping and Figure 19: Low-Carbon Technology).

The McKinsey report also considered the costs of achieving this reduction. A number of different strategies can reduce carbon output, but there is no single silver bullet. Carbon capture and storage (CCS) is an important element in a strategy to achieve emissions reductions, but it is not enough by itself. Energy efficiency, another important source of reductions, can lower the overall cost of reductions because gains from energy savings will offset capital costs. If all of the reductions suggested by McKinsey were implemented, the cost to the economy would be quite low, according to the report.

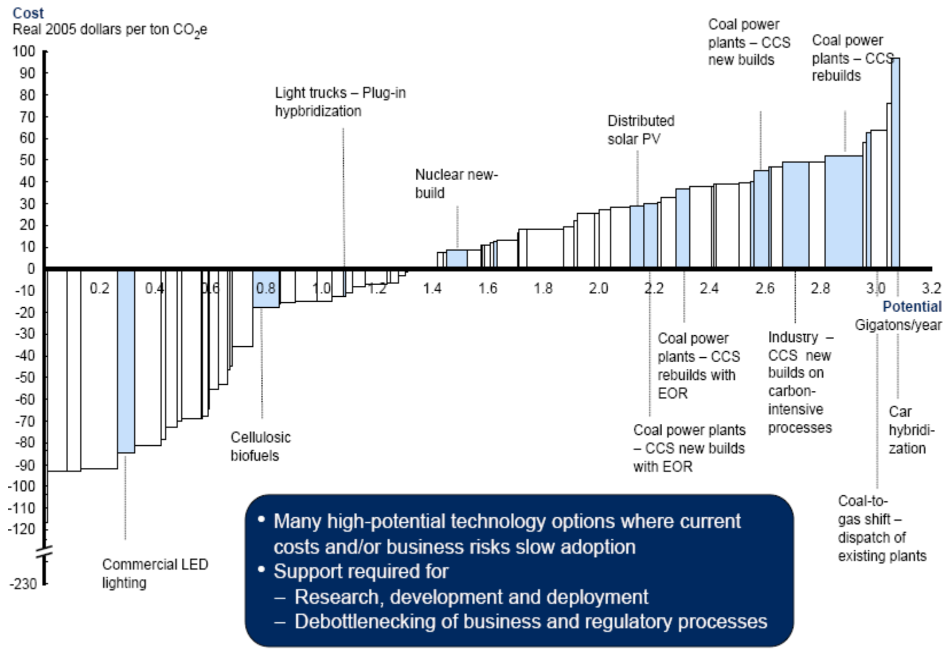
Nyquist emphasized the importance of agreed targets for public policy approaches and called for some form of market mechanism such as cap-and-trade or a market tax to regulate the price of efforts to contain climate change. He noted that policymakers will need to clarify "what targets we are trying to achieve," and warned that it will take extremely high carbon pricing to motivate changes in consumer behavior.

Figure 18: McKinsey's Global Mapping of GHG Abatement Opportunities



Source: McKinsey & Company

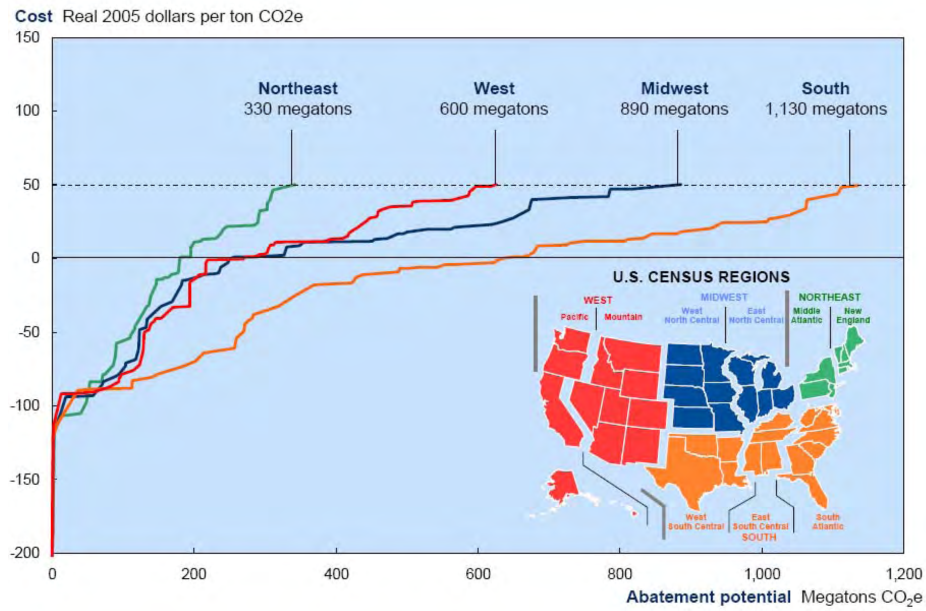
Figure 19: Low-Carbon Technology and Infrastructure Opportunities



Source: McKinsey & Company
Note: 2030 Mid-Range Case: The color blue indicates technology-linked opportunities.

McKinsey estimates that the United States has the potential to reduce emissions by 3.0 to 4.5 $GtCO_2e$; doing so would cost an estimated \$1 trillion between now and 2030, which represents about 1.5 percent of total U.S. capital investment over that period. But the potential for abatement varies by region, according to the McKinsey study (see Figure 20: Geographic Differences). The West has the biggest potential for reductions in power generation, the Midwest in agriculture, the South in buildings and appliances, and the Northeast in transportation. The study also concludes that the industrial sector could have significant opportunities to reduce GHG emissions if the correct incentives are established, but the United States has little opportunity for carbon sinks because there are few significant stretches of land that can be reforested.

Figure 20: Geographic Differences in Abatement Cost: Mid-Range Case to 2030



Source: McKinsey & Company

In his presentation on “Energy Security and Climate Change Policy: Two Sides of the Same Coin?,” Peter Hartley, Baker Institute Rice Scholar and the George and Cynthia Mitchell Chair and professor of economics at Rice University, discussed the ways in which climate policy and energy security concerns might interact in the policy arena. Hartley noted that former British Prime Minister Tony Blair once stated that “We must treat energy security and climate policy as two sides of the same coin,” but Hartley added that in many cases, the two are not always complementary.

In considering energy security, Hartley noted that price uncertainty reduces investment in diversified energy supplies, exacerbating supply and price instability. This instability can be reduced in the short term through emergency stocks such as the Strategic Petroleum Reserve. In the long term, an integrated world market and diverse supply sources, including the type of fuel and number of links between customers and suppliers, will both help to reduce instability. “Greater variety of energy supply sources will be key,” Hartley explained.

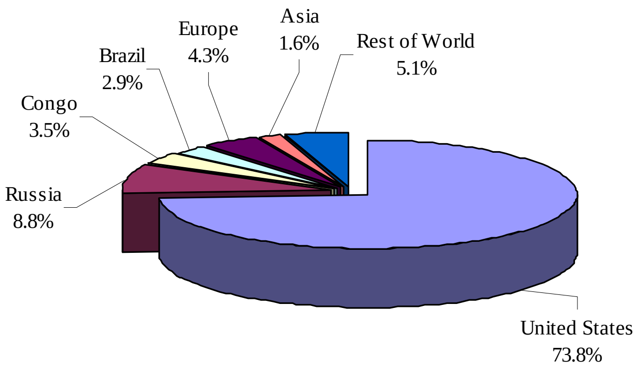
Hartley believed that to some extent, GHG emissions reduction goals and energy security goals can be met through similar policies, since a transition to less carbon intensive fuels would also meet climate-related goals. He noted that improvements in energy efficiency can simultaneously enhance energy security, as greater energy efficiency results in less vulnerability to energy price shocks and provides a policy pathway to reduce GHG emissions. “Increases in energy efficiency will serve both energy security and climate change purposes, as will increasing the use of non-fossil fuel based energy sources,” he said. Hartley quoted the late Nobel laureate Richard Smalley: “What we have is a terawatt problem; what we need to do is bring to the table in the end to save the climate problem, and in the end the energy security problem, a terawatt of clean, affordable energy.” According to Hartley, the only source on the horizon that appears capable of meeting this challenge is solar, but he added it would require major advances in technology.

Hartley proposed that the best way to encourage increases in energy efficiency is to increase energy prices, rather than mandate specific carbon-related regulations. Japan and Western Europe are two examples of regions that have higher energy efficiency due to higher energy taxes.

Hartley noted that energy security and climate change “become significantly less aligned” when the subject of the cheapest available fuel sources is concerned. The United States has 29 percent of the world’s proven reserves of recoverable coal and 74 percent of shale oil, while Canada has 73 percent of global tar sands (see Figure 21: Coal and Unconventional Oil in the United States). “These sources contain a great deal of energy and would be a wise choice from an energy security standpoint,” explained Hartley, “as there is less risk of disruption of supply.” He acknowledged however that from an emissions change standpoint, they are very carbon-intensive ways of generating energy.

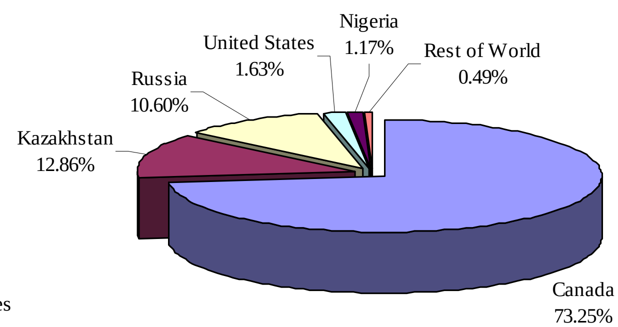
Figure 21: Coal and Unconventional Oil in the United States (2005)

Shale Oil



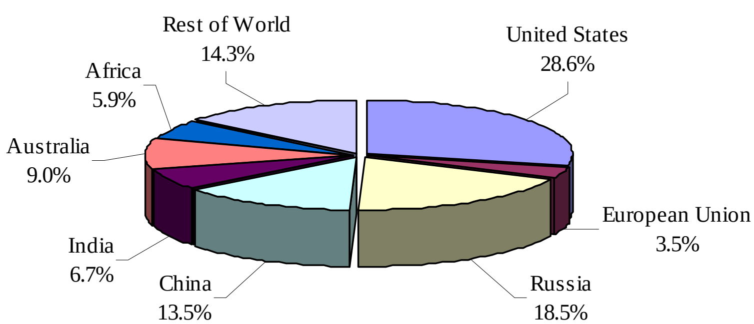
Total = 2.83 trillion barrels

Bituminous Oil in Place



Total = 3.27 trillion barrels

Proved Recoverable Reserves of Coal

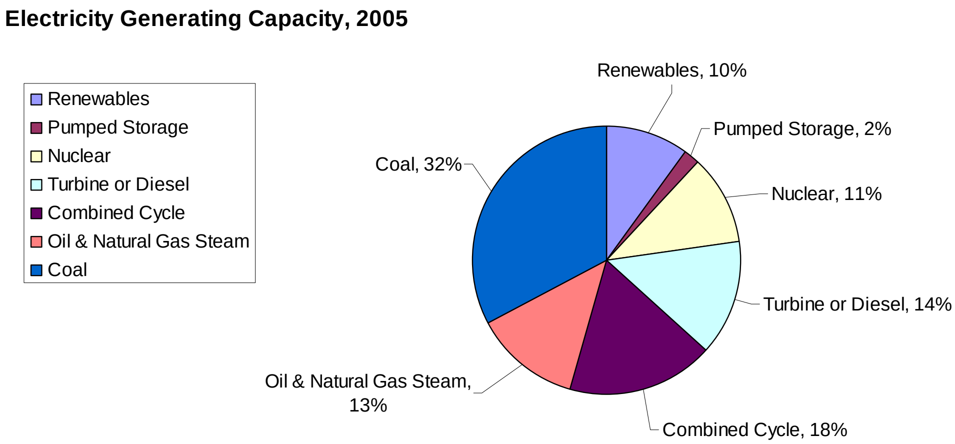


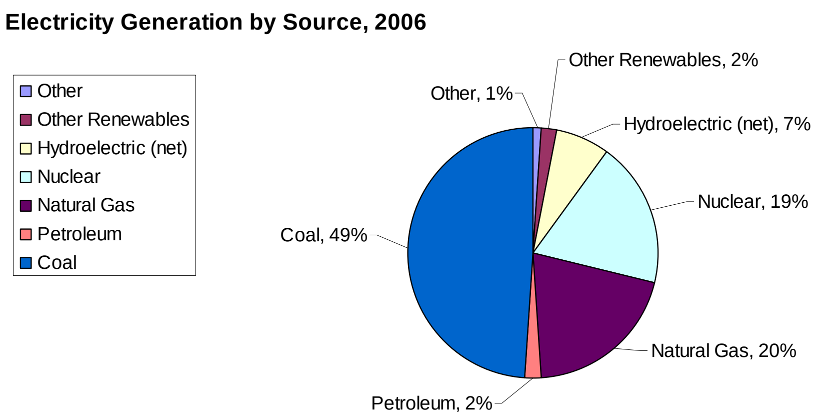
Total = 847.5 billion tons

Source: World Energy Council, Reserves at end of 2005, http://www.worldenergy.org.

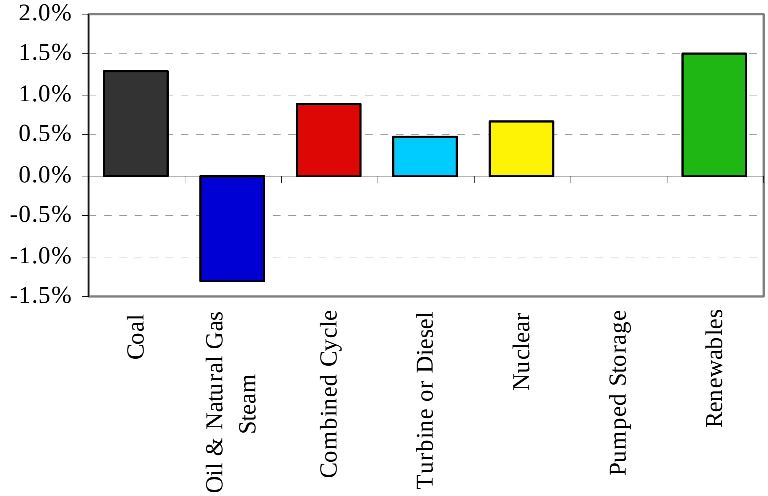
A major portion of U.S. electricity comes from coal (see Figure 22: Sources of U.S. Electricity Generation). If we limit coal increase over the next 25 years, the United States will have to use more natural gas in its power sector. This will mean that liquefied natural gas (LNG) imports will have to grow more substantially in the future. As a result, the United States could become dependent on LNG imports, many of which come from the Middle East (see Figure 23: Reference Case). Thus, a climate policy that seeks to lower coal use could compromise U.S. energy security goals. Hartley argued that a CO_2 tax would favor a shift to natural gas in the short term, which will reduce energy security by increasing U.S. dependence on imported oil and natural gas.

Figure 22: Sources of U.S. Electricity Generation



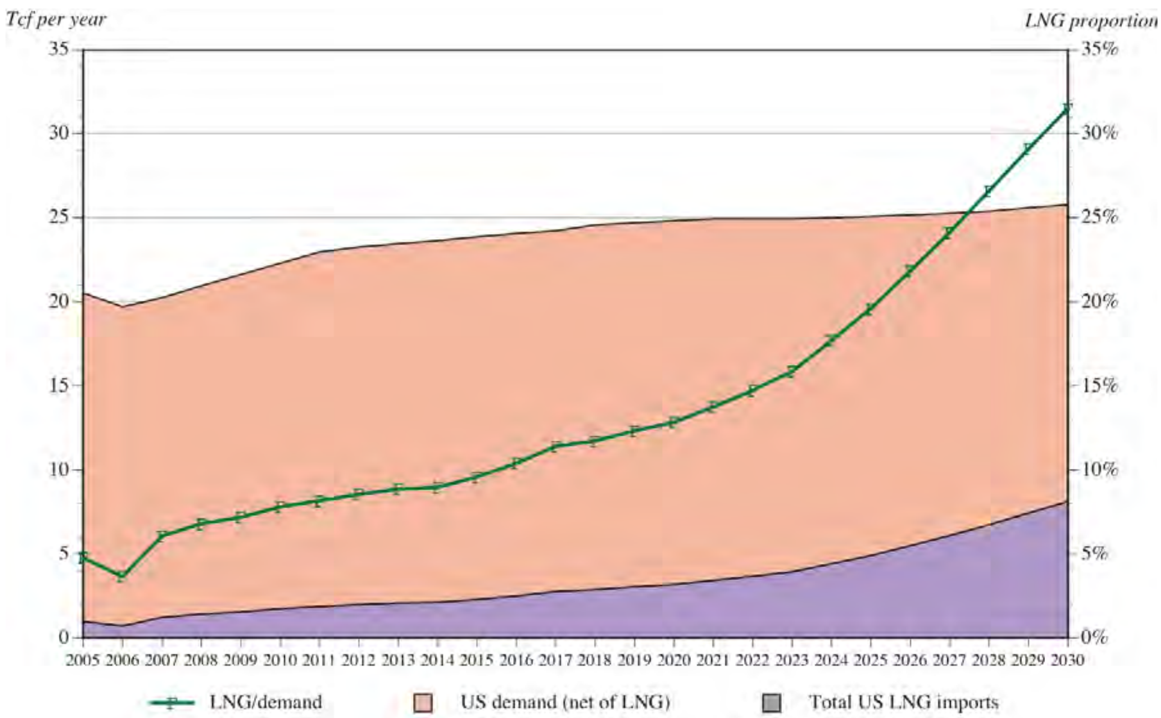


Average Annual Net Capacity Growth, 2005-2030



Source: U.S. Energy Information Administration Annual Energy Outlook, 2008 reference case.

Figure 23: Reference Case - U.S. LNG Imports



Source: Rice World Gas Trade Model, RWGTM runs, January 2008.

Hartley suggested that a tax on energy (rather than a cap-and-trade system or carbon tax) could achieve the same results as a tax on carbon if the proceeds were used to subsidize investments in non-fossil fuel based energy. An energy tax would result in more emissions than other plans but would improve energy security. And in the short term, carbon-intensive fossil fuels would not be handicapped. The revenues could also be used for adaptation measures to alleviate the immediate effects of climate change and as subsidies for research in alternative energy. Hartley argued that carbon taxes would favor alternative fuels that have the greatest immediate profitability, like wind, but may not propel the optimum investment in alternative energy needed for the long term. He noted that wind, for example, does not have the potential to be scaled up to solve our long-term needs. Rather, under an energy tax system, the revenues could be purposely devoted to those energy technologies with the greatest long-term prospects, such as improvements in solar power generation, electricity storage, and energy transmission.

Mort Webster, assistant professor of public policy at MIT, discussed the least costly ways to reduce carbon emissions in his presentation titled “Considering Risk and Uncertainty in Designing Climate Change Policy.” Using an integrated assessment model of the global economy and the energy system along with feedbacks to the climate, MIT has generated forecasts that estimate the economic costs associated with different levels of emission reductions to make cost benefit analysis possible.

The model forecasts out 100 years. Webster warned against the inherent uncertainty of such time frames and of making assumptions about the economics and emission levels of the future. Webster said the MIT modeling exercise concluded that even if the atmospheric concentration of CO_2 stabilized at 550 ppm, or even 750 ppm, there remains a slight probability of reaching a 5˚C change or higher, but the probability is “considerably lower than that with no policy changes.” The uncertainties can also be reduced over time as policy is adapted to new findings and circumstances, he added.

Webster emphasized that “one variable … to take into account in forecasting of costs is the price of energy. If you assume costs of alternative energy are low, then the cost of switching to new forms of energy is low, but the savings achieved from efficiency gains are also lower, thus canceling each other out to some extent."

Webster noted that climate regulation should "aim for some consistency in policy over time," because drastic changes over short time periods (say every five or 10 years) do not "provide enough regulatory certainty." Webster added that MIT's modeling demonstrated that while the ability to learn and adapt is important, waiting 20 years for better information before responding to climate challenges could prove catastrophic. "If we have the ability to learn and adapt our policies relatively quickly, we would set a lower tax on carbon emissions," he explained. "The ability to learn and adapt leads to less stringent policies." He concluded, however, if it takes more than about 20 years, "it is as if we never learn new information, as by that point cumulative emissions will be large."

VI. Technological Options for Dealing with Climate Change: Costs and Benefits

Scientists and economists agree that the mobilization of new, cost-effective, clean technologies will be pivotal to the ability of the United States to develop an effective strategic response to climate change. A successful climate policy will have to include measures that will promote rapid technological development (including broad investment in research and development) and international collaboration. Cost-effective strategies to promote widespread commercial deployment of promising, existing technologies and stimulate new technologies and innovation will also be crucial. The requirements for cleaner energy production and enhanced efficiency are so large that small-scale innovation will not adequately address the challenges. Instead, policies are needed that will promote rapid turnover in billions of dollars of infrastructure to technologies that can be readily scaled up and dispersed with unprecedented market penetration.

BP chief scientist Steve Koonin told conference participants in his keynote address, "Corporate Greenhouse Gas Policies" that "the role of policy is to close the gap between what we will do and what we could do." He added that "science, technology and common sense can combine to produce a list of those qualities that are either essential or highly desirable in the policies that will reduce greenhouse gas emissions."

Koonin stated that climate policy will have to account for energy demands that are expected to double by 2050, emphasizing that emissions will probably have to be reduced by a factor of four. "Modest emissions reductions only delay, but don't prevent, crossing [dangerous] concentration thresholds," Koonin believed.

Koonin emphasized that partial solutions will not be effective and that large multinational corporations such as BP must be part of the solution. "This aspect of materiality means that large corporations must be actively involved in GHG emissions reductions, since it is through them that societies get things done, at least in the developed world," he said. GHG policies will have to be universal, addressing "all emissions and all emitters," he added. Koonin noted that while 60 percent of all anthropogenic emissions come from energy production and use, agriculture and deforestation are also an important cause of warming trends and must be addressed.

Solutions that focus solely on industrial economies will not be effective, Koonin believed, noting that every 10 percent reduction in emissions in the developed world will be counteracted by a four-year increase in economic development globally. Unless the cost of emissions reduction technologies fall to the level of current conventional technologies, he said, "we have to face the question, who will pay the developing world not to emit?"

Policy will be the key to cleaner technologies, Koonin remarked, and delays will only make the problem worse. Climate change policy must be adopted quickly because energy infrastructure is not easily replaced or retired from service. "Apart from universality, greenhouse gas policies must also be timely. One of the defining characteristics of the energy infrastructure is its longevity," he explained. "Power plants last 50 years, automobiles last 20 years, and buildings in which half the world's energy is used last about 100 years." Infrastructure currently under construction is locking in future emissions for decades, Koonin added, warning that "we have little time to set the policies right."

Koonin noted that business is already acting to cut emissions, with firms, like BP and Wal-Mart, taking an early lead resulting in a decade of experience with emissions reductions that made business sense. But to reach the higher reduction levels required across the board, better regulatory and economic frameworks will be needed, Koonin said. “Assigning costs [to GHG emissions] is an essential policy measure that is now being implemented spottily around the world,” he added.

Carbon must be priced correctly before it can be used as an incentive to reduce GHG emissions, Koonin explained. “If cost is less than $20 per ton, you’re just not serious.” But he claimed that a carbon cost above $40 a ton would have significant impact on consumers, potentially creating political stresses. Therefore, climate policy must be “technically informed,” he said, because the knowledge will propel cost-effective technologies that have the greatest potential for rapid scale-up. “Maybe there are no silver bullets, but some bullets have a bigger caliber than others, and those are the ones we need to be pursuing,” he stated. Given the long lead time to develop infrastructure, “continuity in greenhouse gas emissions policy is also essential,” he added. Policies will need to be isolated from politics as much as possible, much the way “we use the U.S. Federal Reserve Bank to isolate monetary policy [from politics].”

“We need GHG policies to be material, universal, timely, cost-effective, focused, technically informed, and continuous,” Koonin concluded. “We also need them to promote conservation, education, and new ties between industries and academia.” Closer ties between industry and academia will be needed to address the challenge of emissions and energy security, he added.

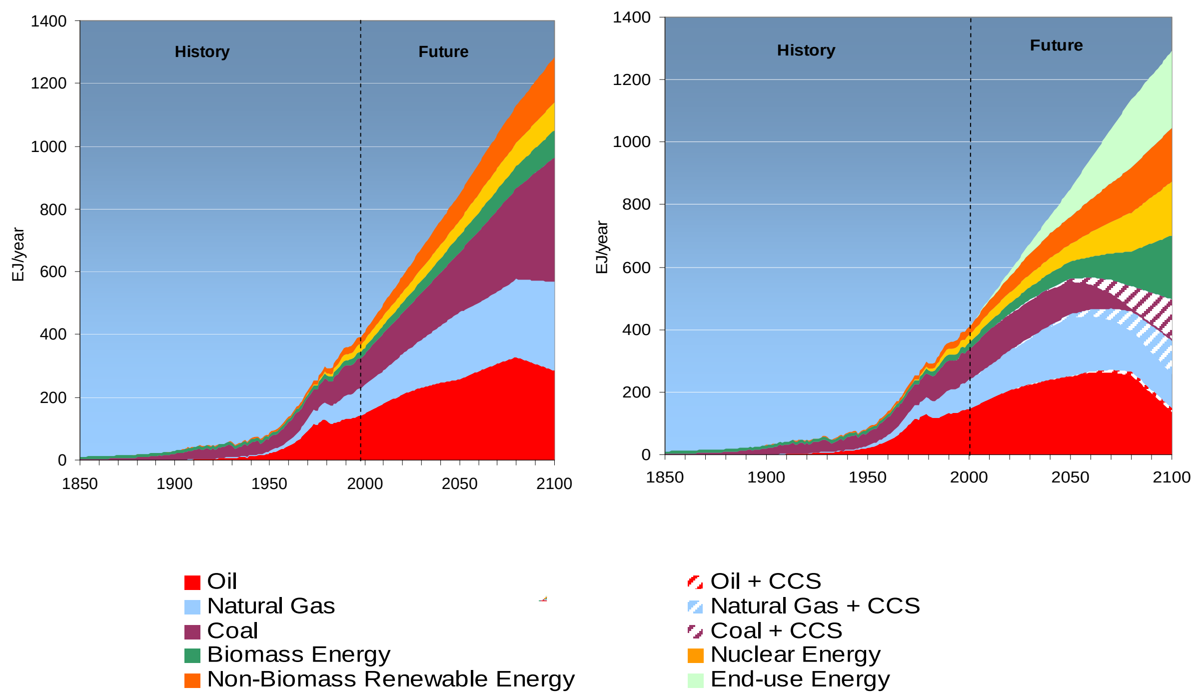
James “Jae” Edmonds, chief scientist and laboratory fellow at the Joint Global Change Research Institute, discussed key findings of the Global Energy Technology Strategy Project (GTSP) during his talk, “Energy Technology and Greenhouse Gas Emissions Mitigation.” The study looked at the impact of CO_2 stabilization on the global energy system and the impact of rising carbon prices on economic sectors and regions (see Figure 24: Impact of CO_2 Stabilization and Figure: 25 Impact of Rising Carbon Prices).

According to Edmonds, climate change represents a long-term, stock pollution problem, as opposed to a flow-pollution problem. To stabilize atmospheric concentrations of CO_2, the global energy system must be fundamentally changed, with technology playing a central role. “The way to think about technology is not ‘Can I stabilize concentration with known technologies?’”

Edmonds said. "Of course you can. The role of technologies is about controlling costs." Edmonds noted that although technology costs do decline over time, the matter of future affordable technologies reducing the cost of carbon controls is "not about a decline in the cost curve," as more expensive technologies will be needed to achieve more stringent reductions in emissions.

Figure 24: Impact of CO_2 Stabilization on the Global Energy System

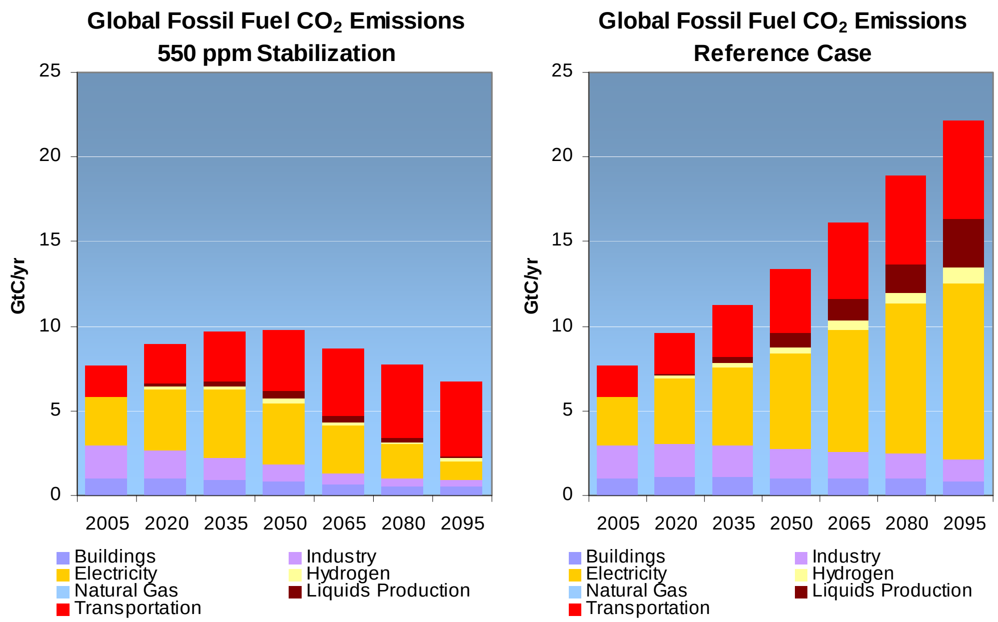
Historical Case with pre-industrial CO_2 concentration ~280 ppm and Reference Case in 2100 with CO_{2c}Concentration ~740 ppm (first graph) or ~550 ppm (second graph).



Source: Global Energy Technology Strategy Addressing Climate Change: Phase 2 Findings from an International Public-Private Sponsored Research Program, J.A. Edmonds et al., May 2007.
Note: Dashed Line in Figure represents present CO2 Concentration ~380 ppm

Figure 25: Impact of Rising Carbon Prices on Economic Sectors and Regions

Historical case with pre-industrial CO_2 concentration ~280 ppm and reference case in 2100 with CO_2 concentration ~740 ppm (first graph) or ~550 ppm (second graph).



Source: Global Energy Technology Strategy Addressing Climate Change, 2007.
Note: Stabilization changes the sources of fossil CO_2 emissions. Utility emissions drop to virtually zero. Transportation emissions dominate. The response to escalating carbon prices will vary across economic sectors and regions.

In Edmonds' opinion, change based on currently available technologies should begin immediately. He highlighted six types of technology to be deployed: CO_2 capture and storage; biotechnology; hydrogen systems; nuclear energy; wind energy; and, solar energy. But he added, many additional technologies that will be "deployed don't have a name because they haven't been invented yet."

MIT physics professor Ernest Moniz discussed the "Viability of Carbon Capture and Sequestration as a Mitigation Approach." Moniz noted that CCS technology "is the key enabling technology for coal use in a carbon constrained world." But he warned that it would take a tax of around $30 per ton in order for mature gasification technology with carbon capture to be economical.

The challenge for the United States, China and India will be to increase coal consumption while reducing emissions, Moniz said. These three countries combined account for roughly 40 percent of global coal consumption. In the United States, coal contributes to about 40 percent of total CO_2 emissions. Under most scenarios, Moniz's research shows that coal consumption will continue to grow even with higher carbon taxes (see Figure 26: Scenarios of Coal Consumption in the Presence of a Carbon Tax).

In the MIT study *The Future of Coal*, economic modeling showed that the market price necessary to trigger a switch to CCS would not be reached until 2020. "It's 15 to 20 years even after you have the price signal that you begin to get large penetration and large impact … and with the price signal it's still going to take a long time for the technologies to penetrate at a large scale," Moniz noted. He added that there should be a sense of urgency. "If we wait 20 more years, it's 20 more years to introduce."

CCS and geologic sequestration technologies are promising, but problems still remain. While CCS technology is proven, the scale is a major issue, he said. Basic research is also needed to improve cost and performance, because current technology is prohibitively expensive. An extensive technical program is needed to resolve scientific issues related to the storage of massive quantities of CO_2, he added. Furthermore, public support will be necessary for the construction of billion-barrel reservoirs around plants. Immense infrastructure issues require further study, Moniz noted, and a broad range of regulatory questions regarding permitting, liability, monitoring and other issues remain unresolved.

Moniz thought it is a shame that the U.S. Department of Energy shelved a FutureGen CCS integrated system demonstration due to cost escalations. He said there is an urgent need to put a 10 to 15 year research and demonstration program in place and that it must operate on a large scale to satisfactorily resolve issues.

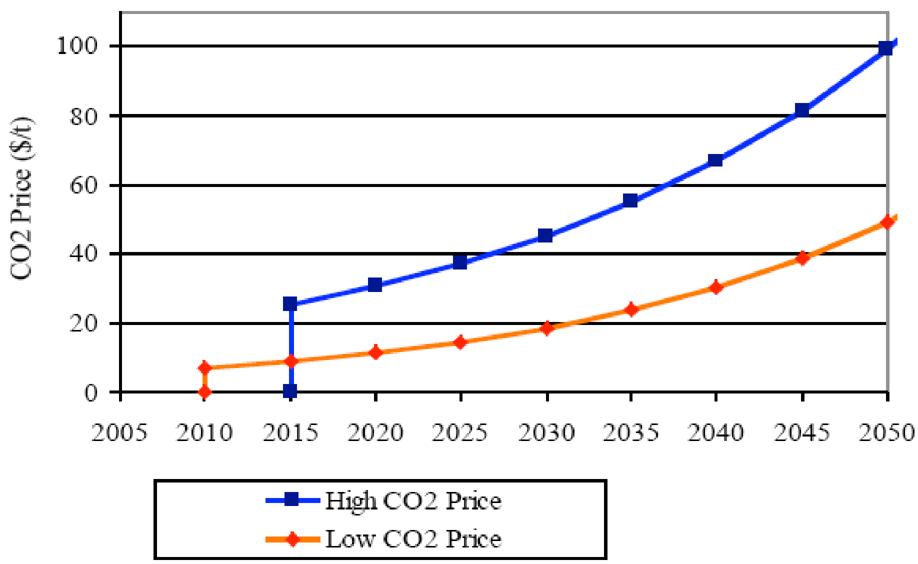
Figure 26: Scenarios of Coal Consumption with Carbon Pricing

*Part I: Coal Consumption with and without CCS in Exojoules (EJ)**

	BAU		High CO_2 Price	
	2000	2050	With CCS	Without CCS
Global	100	441	***159***	***99***
U.S.	24	59	43	24
China	27	85	38	19

** Universal, simultaneous participation, limited nuclear and EPPA-Ref gas prices.*
Source: Massachusetts Institute of Technology, 2007, The Future of Coal :Options for a Carbon-Constrained World, Table 2.11.

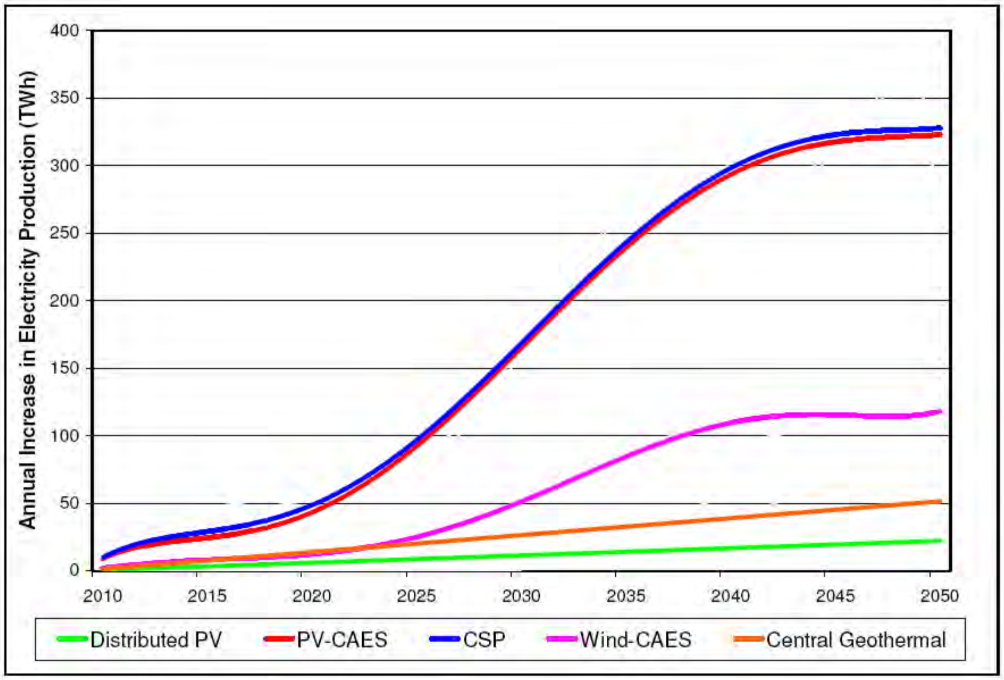
Part 1I: Scenarios of Penalties on CO_2 Emissions in Cost per Ton ($/t)



Source: The Future of Coal, Figure 2.2

Ken Zweibel, president of PrimeStar Solar, began his presentation, "The Solar Grand Plan," by noting that new ways of making electricity should be carried out on a very large scale, and that this requires a different way of thinking. A massive switch from coal is needed, Zweibel stated. Solar power plants could supply 69 percent of the U.S. electricity by 2050 (see Figure 27: Annual Increases in Electricity Production). "Concentrated sources of energy and photovoltaic are closer [in terms of prices] to where we need them to be than we think," he said.

Figure 27: Annual Increases in Electricity Production from Select Generating Facilities



Source: Ken Zweibel, "American Solar Action Plan," Congressional testimony submitted to the House Science and Technology Committee, March 2008.
Note: Unit of Measurement – Terawatt hours (TWh).
Types of electricity generating facilities: photovoltaic plant (PV); PV plant coupled with Compressed Air Energy Storage gas turbine power plant (PV-CAES); concentrated solar power plant (CSP); wind plant coupled with a CAES gas turbine power plant (Wind-CAES).

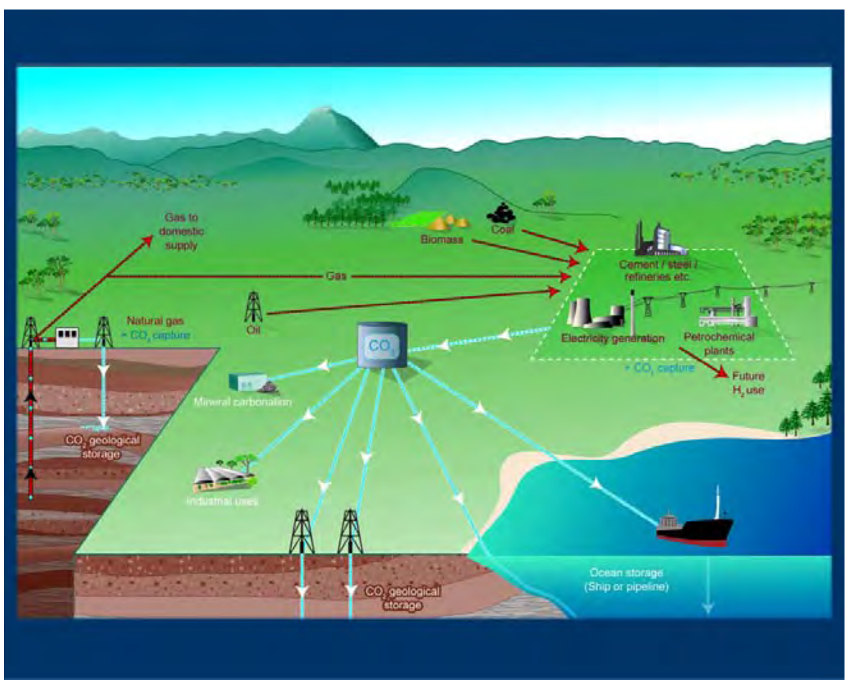
Zweibel acknowledged that economical storage technology will be a critical component of a grand solar strategy. In one idea, a vast area of photovoltaic cells could be erected in the U.S. Southwest. Excess daytime energy could be stored as compressed air in underground caverns and tapped during nighttime hours. However, the cost of the compressed air storage system currently adds 40 percent to the cost of electricity.

According to Zweibel, another major solar energy initiative would utilize large solar concentrator power stations and a new direct current power transmission main line to deliver the solar energy to other parts of the country. He added that plug-in hybrid vehicles are essential for a successful solar grand plan, because they would allow for a shift to electricity in the transportation sector.

Solar energy incentives are needed to encourage widespread use of technologies such as photovoltaic panels, concentrated solar power systems, compressed air energy storage, and thermal storage, Zweibel concluded. If a major program were put in place, solar energy could be "a silver bullet" solution in the next 10 to 15 years.

Cal Cooper, science fellow at ConocoPhillips, discussed the business potential of CCS in his presentation "The Dimensions of the Prize: Leverage Technology to Achieve Sustainable Emissions." He stated that CCS could be an essential technology for capital-intensive industries (see Figure 28: Carbon Capture and Storage Scheme). CCS could also provide employment, generate GDP and drive development of "lots of very cool technology," Cooper said. "To make a meaningful impact on atmospheric CO_2 loads, we need to do more than improve efficiency, more than dramatically increase renewables," he added. "A whopping 20 percent of the emissions reductions we expect by 2050 will have to come from something like CCS."

Figure 28: Carbon Capture and Storage Scheme



Source: Intergovernmental Panel on Climate Change

"In the CCS world, it's not a challenge to have a technology that works, it's a challenge to drive down that cost so it's widely adopted, a challenge that will integrate innovation," he explained. "Technical creativity is needed. We need to think of incentives to speed up the process of building a better mousetrap."

Cooper noted that no single company wants to make billion-dollar investments in CCS because of the high risks involved. "Early movers fear investing in technology that may quickly become obsolete," he said, pointing out that no single winner can clean up the losses of other companies. "We need to talk seriously about an investment structure that will make the downsides acceptable." A system that allows companies to pool risk should be developed, he said.

"We have a pretty good idea of how to do carbon capture and sequestration" Cooper stated, referring to the energy industry's extensive experience using CO_2 for enhanced oil recovery. "The challenge is to make the process more energy and fuel efficient." In order to improve capture technologies, the industry will need better solvent, membrane, and combustion alternatives, he remarked. Cooper also noted that current capture technologies use a lot of energy and the technology under consideration "requires building a big infrastructure to prove it." He added that systems that combust biomass waste and capture the CO_2 through gasification have excellent potential.

Cooper remarked that geologic basin storage poses little risk if sites are chosen carefully. For example, North America has a great number of CO_2 storage sites with good potential. According to Cooper, ConocoPhillips has a number of projects under consideration that would enable CCS, including storage of more than 1.6 gigatons of CO_2 into gas reservoirs in the North Sea. However, Cooper explained it will be difficult to go forward with the project until the company has "a better fix on the carbon price" and confidence that the price will be "large enough to justify investment." Developing CCS technologies is often compared to the Apollo program, Cooper concluded. But, he added, it is not a centralized mission by a government agency such as NASA. It is a "global mission."

VII. Closing Remarks

In closing remarks to conference participants, Eric Barron, dean of the Jackson School of Geosciences at the University of Texas at Austin, said that the academic community should work together to find solutions to global warming. “We know that we have a problem with climate change, but we lack the earth management sciences to address it effectively,” he stated.

“We have 50 years of intensive climate model development that has been growing, and it’s being coupled to what amounts to a cottage industry of ecosystem modelers, environment and human health modelers,” Barron observed. “But it does not even come close to thinking of the multiple stresses—both the land uses and the pollutants—not to mention climate change.”

He suggested that the academic community evolve from independent climate services and modeling efforts to environmental “intelligence” centers. These would provide cohesive observation frameworks that would make the same information available to all organizations. Central sources of information could also provide an opportunity to develop regional predictive models to improve forecasting and analyze approaches that are ineffective, he proposed.

Barron concluded by noting that neither calling climate change a hoax nor stressing fears is a good method for motivating the public to support the kinds of policies that will be needed. “We have to respond to both adaptation and mitigation, but we do not know the balance,” he stated. “Our current level of knowledge is not great enough to know how much either will cost.”

VIII. Conclusion

Participants at the one-day conference, “Beyond Science: The Economics and Politics of Responding to Climate Change,” highlighted the need for both mitigation and adaptation strategies to address the challenges of climate change. Many participants advocated for a stronger regulatory system for GHG emissions, but there was no consensus on which regulatory system-models would be most effective. Experts do agree, however, that there is an urgent need for additional funding for energy technology research and development, and that a major effort to enhance energy efficiency and develop greener energy, fuel, and electricity generation systems is crucial.

A major conclusion of the conference is that no single policy or technology, no hypothetical "silver bullet" strategy, exists to combat climate change. Instead, the issue will require a variety of policies constituting what one speaker referred to as the "silver shotgun" approach. In addition, both mitigation and adaptation strategies must be adopted and have important, complementary roles. In the United States, so far, proposed legislation has focused on mitigation strategies that drive GHG emissions reductions via regulation. However, over time, the United States will need to develop a more comprehensive approach to climate change to combat the most urgent environmental problems of this century. Thorough, far-reaching policies that encompass a more proactive international diplomatic effort, a stronger science and technology research and development program, carbon emissions regulations, and adaptation strategies for the protection of vital infrastructure and human coastal populations must be implemented.

Among the mitigation strategies currently under consideration in the United States are regulatory measures such as cap-and-trade systems, a low-carbon fuel standard, and regulatory emissions caps and taxes designed to encourage industries and other large users of energy to reduce emissions. Other possible mitigation strategies could include large-scale projects such as reforestation and carbon scrubbing, as well as investment in research and development, targeting innovations that decrease carbon intensity and energy consumption. The Energy Independence and Security Act of 2007, signed into law last year, will reduce U.S. emissions by improving car mileage standards, lowering the amount of fuel that is burned by U.S. automobiles and, hence, U.S. emissions from the transport sector.

Widespread adaptation measures must also be introduced. These measures should be in line with the U.N. MDGs to reduce poverty, disease, and ensure environmental sustainability. In a world of increased flooding, droughts, and storm severity and frequency, policies must identify and account for vulnerable regions that will be hardest hit by rapid changes in climate, weather or local environment. Comprehensive policies must also expand adaptation research and improve monitoring and early warning systems. Furthermore, institutional capacity should be enhanced to plan for climate change consequences and integrated into social networks.

Currently proposed policies to address climate change and energy security concerns are drawn from a patchwork of state legislation, federal mandates, and international agreements. As discussed at this conference, California's emissions legislation could exemplify a possible federal approach to climate and energy security concerns, though varied regional interests could make it difficult to pass sweeping measures on a national level.

Conference speakers indicated that many experts believe a cap-and-trade system will likely emerge as the preferred method of regulating anthropogenic GHG emissions. Under this system, carbon-pollution permits bought and sold at market prices would help limit and reduce carbon emissions. Although other policy models such as carbon or energy taxation strategies could be more effective in theory, they are not likely to be politically popular in the United States and may face public backlash, according to many conference participants.

A carbon tax might effectively reduce carbon emissions and provide revenues that could help fund research and development of energy technologies and mitigation and adaptation measures. However, it could be challenging to plan optimal tax levels and structures given large uncertainties regarding future economic trends, the pace and costs of technological change, and the exact timing and scale of climate event impacts. An alternative policy approach could combine a cap-and-trade system with a carbon fee, but the policy structure of the carbon fee would need to account for the unequal distribution of economic burdens. Research shows that a carbon tax or a cap-and-trade system that sets a carbon fee will be regressive; that is, poorer U.S. households will pay a disproportionate share of income to cover the higher energy costs associated with carbon pricing. Moreover, a cap-and-trade system that does not auction all permits will essentially distribute revenues through the political process to industry. Thus, it is important that a cap-and-trade system is designed in a manner that does not unduly subsidize emissions producers. More public awareness and debate is needed on the pros and cons of different design options for a federal cap-and-trade program.

Despite its drawbacks, a cap-and-trade system is considered one of the most likely tools to successfully reduce carbon emissions, and may also have the greatest chance of winning support in the U.S. Congress. It is the simplest to construct (both politically and publicly) and has a successful precedent in the E.U. The European cap-and-trade system (Emission Trading Scheme or ETS) aims to produce a transparent carbon market with a level of certainty for investors. However, several lessons can be learned from the difficulties encountered during initial ETS implementation. An over-allocation of permits (partly due to incorrect emissions data) greatly hindered the success of the first phase of the ETS and led to a carbon price that was too low to stimulate targeted emission reductions. The E.U. also learned that banking of credits without limitation was necessary to protect carbon market price stability. Finally, the E.U. experience demonstrated that a high percentage of credits sold at auction only (as opposed to given away for free by the government) can prevent dangerous market distortions and ensure greater investment in low-carbon technologies. The European experience also highlights the importance of a well-designed system for international offsets so that a cap-and-trade system does indeed lead to true reductions in GHGs.

Some experts at the conference argued that an energy tax could be more effective than specific carbon legislation if the proceeds were directly spent on developing better low-carbon energy alternatives. This is because a carbon tax will shift players to the currently cheapest immediate alternatives such as wind and biofuels. A carbon tax will not necessarily propel investment in technologies such as solar energy or carbon sequestration, which have better long-term potential for massive scale up but require more research and development to become commercially viable. A more generalized energy tax would also avoid problems associated with a too-sudden shift away from domestic coal supplies to less secure, imported natural gas. Such a sudden shift could have negative consequences for energy security in the short run. As illustrated by successful policies in Japan and Western Europe, energy security concerns may be best addressed by an energy tax, which increases energy prices but lowers overall energy demand and promotes energy efficiency. Still, while energy efficiency is one way to achieve climate goals, a general energy tax could fail to meet emissions goals over the short term, because it would not necessarily discourage coal use. Like the carbon tax, an energy tax would also be politically unpopular as a stand-alone measure in the United States.

Any transition to new GHG regulations and innovative green energy technologies will require flexible policy structures that allow redirection as circumstances change. Additionally, action in the short term requires a combination of large projects and smaller, low-cost measures such as consumer conservation. Consumer responses, like using more efficient light bulbs, insulating homes, and turning off lights, will be crucial to a successful transition to a carbon-constrained world.

Another major aspect of climate change policy is the need to improve existing technologies. Improved technology will promote increased efficiencies, and the savings that result will have the potential to offset investment costs. For the greatest measure of success, policymakers should focus on encouraging the development and use of cost-effective strategies such as CCS technologies, biofuels, and solar power. However, policy should not "pick winners" from among the various alternative and renewable energy technologies, but rather allow the technologies best suited for the nation's needs to rapidly develop and spread.

In the business-as-usual scenario, climate change has the potential to dramatically impact most aspects of life on earth, including social and political stability, economic development, and the health of humans as well as the environment. Although the exact path that climate change policy will take in the coming decades is relatively uncertain, immediate and concerted action, setting nations on a more restrained and environment-conscious path, is necessary to mitigate the damage already done to the environment and adapt behaviors and systems to create a sustainable future. It is important to put policies in place quickly, because energy infrastructure is not easily replaced or retired from service. With every delay, future emissions are being locked in for decades by the traditional infrastructure currently under construction.

The conference was supported by the Science & Innovation Section of the British Consulate-General in Houston, the Baker Institute Science and Technology Policy Program and the Baker Institute Energy Forum.

Appendix I: List of Acronyms

AB 1493 = Assembly Bill 1493 also known as the "Pavley Law"

AGU = American Geophysical Union

BAU = Business As Usual

Btu = British thermal unit

CAA = Federal Clean Air Act

CAES = Compressed Air Energy Storage

CAFE = Corporate Average Fuel Economy

CARB = California Air Resources Board

CCS = Carbon Capture and Storage

CDM = Clean Development Mechanism

CFCs = Chlorofluorocarbons

CO_2 = Carbon Dioxide

CRS = Congressional Research Service

CSP = Concentrated Solar Power

E = Energy

ECU = European Currency Unit

EIA = U.S. Energy Information Administration

EJ = ExaJoule (10^8 joule)

EPA = Environmental Protection Agency

ETS = Emission Trading Scheme

EU = European Union

EUR/tCO_2e = Euro per ton of Carbon Dioxide emitted

GDP = Gross Domestic Product

GHGs = Greenhouse Gas Emissions

GJ = GigaJoule (10^9 joule)

Gt = Gigaton

$GtCO_2e$ = Gigaton Carbon Dioxide Emitted

GTSP = Global Energy Technology Strategy Project

HIV/AIDS = Human Immunodeficiency Virus/Acquired Immunodeficiency Syndrome

HR 6 = U.S. Congress House Resolution 6, also known as the "Energy Independence and Security Act of 2007"

IPCC = Intergovernmental Panel on Climate Change

JI = Joint Implementation

KG = Kilogram (10^3 grams)

LCFS = Low-Carbon Fuel Standards

LNG = Liquefied Natural Gas

MDGs = United Nations Millennium Development Goals

MIT = Massachusetts Institute of Technology

Mt = Metric ton (1000 kg)

NCAR = National Center for Atmospheric Research

NSES = National Science Education System

PPM = Parts Per Million

PV = Photovoltaic

RGGI = Regional Greenhouse Gas Initiative

TWh = Terawatt Hour (10^{12} watt hour)

UN = United Nations

UNSEG = United Nations Scientific Expert Group

VMT = Vehicle Miles Traveled

WCI = Western Climate Initiative

WHO = World Health Organization

Appendix II:
Conference Agenda and Bios
from the
February 2008 Baker Institute conference,
“Beyond Science: The Economics and Politics of
Responding to Climate Change”

Beyond Science:

The Economics and Politics of Responding to Climate Change

Saturday, February 9, 2008

Conference Agenda

Welcoming Remarks

8:00am **The Honorable Edward P. Djerejian**
Founding Director, James A. Baker III Institute for Public Policy, Rice University

Keynote Address

8:15 am The Road from Bali: The Future of American Policy on Global Climate Change
The Honorable John Kerry
United States Senator from Massachusetts

Opening Addresses

8:50 am Introduction
Neal F. Lane, Ph.D.
Senior Fellow in Science and Technology Policy, James A. Baker III Institute for Public Policy, and Malcolm Gillis University Professor, Rice University

Address: International Panel on Climate Change 2007 Report and Climate Change Modeling
Timothy L. Killeen, Ph.D.
Director, National Center for Atmospheric Research

Discussion: Confronting Climate Change: The Sigma Xi/UN Foundation Report
Rosina M. Bierbaum, Ph.D.
Dean and Professor, School of Natural Resources and Environment, University of Michigan
John P. Holdren, Ph.D.
Teresa and John Heinz Professor of Environmental Policy, Kennedy School of Government, Harvard University, and Director, Woods Hole Research Center

Break

Morning Addresses: Policy Approaches to Limit Carbon

Moderator: Amy Myers Jaffe, Wallace S. Wilson Fellow in Energy Studies, James A. Baker III Institute for Public Policy, Rice University

10:25 am The California Model for Combating Climate Change
Daniel Sperling, Ph.D.
Professor of Civil Engineering and Environmental Science and Policy and
Founding Director, Institute for Transportation Studies, University of California, Davis

Cap and Trade Systems: The European Experience
Milo Sjardin
Head, New Carbon Finance, North America

A Carbon Tax Swap: An Equitable Tax Reform to Address Global Climate Change
Gilbert E. Metcalf, Ph.D.
Professor of Economics, Tufts University

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Lunch Keynote

12:00 pm

Introduction
Paul Lynch
HM Consul-General, British Consulate-General Houston
Neal F. Lane, Ph.D.
Senior Fellow in Science and Technology Policy, James A. Baker III Institute for Public Policy, and Malcolm Gillis University Professor, Rice University

A Corporate View of Greenhouse Gas Policies
Steven E. Koonin, Ph.D.
Group Chief Scientist, BP p.l.c.

Afternoon Session I – Economic Issues of Climate Change Policy

Moderator: S. Malcolm Gillis, Ph.D., University Professor, Ervin K. Zingler Professor of Economics and former President, Rice University

1:30 pm

The Economic Impact of Climate Change: The Stern Report
Dimitri Zenghelis
Head, Stern Review Team, Office of Climate Change, HM Treasury

Economic Costs of Climate Change
John P. Weyant, Ph.D.
Professor of Management Science and Engineering and Director, Energy Modeling Forum, Stanford University

Reducing U.S. Greenhouse Gas Emissions: At What Cost?
Scott S. Nyquist
Director, McKinsey & Company

Global Climate Change Policy and Energy Security: Two Sides of the Same Coin?
Peter Hartley, Ph.D.
Baker Institute Rice Scholar, George and Cynthia Mitchell Chair and Professor of Economics, and Academic Director, Shell Center for Sustainability, Rice University

Considering Risk and Uncertainty in Designing Climate Change Policy
Mort Webster, Ph.D.
Visiting Assistant Professor, Massachusetts Institute of Technology (MIT)

Break

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Afternoon Session II – Options for Dealing with Climate Change: Costs and Benefits
Moderator: Robert Harriss, Ph.D., President and CEO, Houston Advanced Research Center

4:00 pm	Energy Technology and Greenhouse Gas Emissions Mitigation **James A. Edmonds, Ph.D.** Laboratory Fellow and Chief Scientist, Joint Global Change Research Institute, Pacific Northwest National Laboratory
	Coal in a Carbon-Constrained World **Ernest J. Moniz, Ph.D.** Cecil and Ida Green Professor of Physics and Engineering Systems and Director, MIT Energy Initiative, Massachusetts Institute of Technology (MIT)
	The Solar Grand Plan **Ken Zweibel** President, PrimeStar Solar
	The Dimensions of the Prize: Leverage Technology to Achieve Sustainable Emissions **Cal Cooper, Ph.D.** Science Fellow, ConocoPhillips Technology

Closing Comments

6:00 pm	Introduction **Emil Peña** Executive Director, Energy and Environmental Systems Institute (EESI), Rice University
	Gaining Traction Beyond the Science of Climate Change **Eric J. Barron, Ph.D.** Dean, Jackson School of Geosciences, The University of Texas at Austin
	Reception Courtesy of UK Science and Innovation Section, British Consulate-General Houston

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The Economics and Politics of Responding to Climate Change

Saturday, February 9, 2008

Speaker Biographies

Eric J. Barron, Ph.D., who has served as dean of the Jackson School of Geosciences at The University of Texas at Austin since 2006, began a career in geology as an undergraduate at Florida State University. He earned a master's degree (1976) and a doctorate (1980) in oceanography from the University of Miami. His career turned to climate studies in 1976 with a Cray Supercomputing Fellowship from the National Center for Atmospheric Research (NCAR). Barron then joined NCAR as a postdoctoral research fellow and later became a research scientist in the global climate modeling group. In 1985, he returned to the University of Miami as associate professor. Barron went to Pennsylvania State University in 1986 to direct the College of Earth and Mineral Sciences' newly formed Earth System Science Center (ESSC). Under Barron's leadership, the growth of ESSC resulted in the establishment of the College of Earth and Mineral Sciences' Environment Institute, which included ESSC and a group of other research centers. Barron became the director of this new institute in 1998. He earned the title of distinguished professor in 1999. In 2002, he was named dean of the College of Earth and Mineral Sciences at Penn State. Barron's research interests are in the areas of climatology, numerical modeling and Earth history.

Rosina M. Bierbaum, Ph.D., became dean of the School of Natural Resources and Environment (SNRE) at the University of Michigan in October 2001. Previously, Bierbaum served in environmental science policy leadership positions in both the legislative and executive branches of government, culminating in her post as director of the Environment Division of the White House Office of Science and Technology Policy, a Senate-confirmed position. In that role, she served as the administration's senior scientific advisor on a wide range of national and international environmental issues, including air and water quality, endangered species, biodiversity, ecosystem management, endocrine disruptors, global change, and energy research and development. She led four U.S. delegations to the Intergovernmental Panel on Climate Change. Bierbaum has been elected a fellow of the American Academy of Arts and Sciences and the American Association for the Advancement of Science. Among other awards, she has received the Waldo E. Smith Medal from the American Geophysical Union in recognition of extraordinary service to geophysics and the Climate Protection Award from the U.S. Environmental Protection Agency. Bierbaum received her Bachelor of Science in biology and Bachelor of Arts in English from Boston College, and earned her doctorate in ecology and evolution at the State University of New York, Stony Brook.

Cal Cooper, Ph.D., is a science fellow at ConocoPhillips Technology in Houston where his current focus is leading efforts in carbon capture and storage. He serves on the executive boards of the CO_2 Capture Project (CCP2), the Australian CO_2 Cooperative Research Centre (CO2CRC), and the EU CO_2 Research Monitoring Verification Program (CO2ReMoVe), in addition to various advisory panels of the U.S. Department of Energy, the International Energy Agency and the Society of Petroleum Engineers. His leadership roles in ConocoPhillips have included chief geologist of upstream technology and managing several geosciences organizations. Besides greenhouse gas control, Cooper's research spans from hydrocarbon exploration and basin analysis to folded belts, tectonics, mud volcanoes and seismic processing algorithms. Cooper received a doctorate in geology and geophysics from Rice University, a Master of Science in geology from the State University of New York, Albany, and he earned his undergraduate degree in geophysical sciences at the University of Chicago.

The Honorable Edward P. Djerejian is the founding director of the James A. Baker III Institute for Public Policy. He served both President George H.W. Bush and President William J. Clinton as assistant secretary of state for Near Eastern Affairs and Presidents Reagan and Bush as U.S. ambassador to Syria. He served President Clinton as U.S. ambassador to Israel before completing his foreign service career in 1994. He also served President Reagan as special assistant and deputy press secretary for foreign affairs. He has been awarded the Presidential Distinguished Service Award, the Department of State's Distinguished Honor Award, and numerous other honors including the Ellis Island Medal of Honor and the Anti-Defamation League's Moral Statesman Award.

James A. Edmonds, Ph.D., is laboratory fellow and chief scientist at the Pacific Northwest National Laboratory's (PNNL) Joint Global Change Research Institute, and adjunct professor of public policy at the University of Maryland at College Park. Edmonds is the principal investigator for the Global Energy Technology Strategy Program to Address Climate Change, an international, public-private research collaboration. His research — in the areas of long-term, global energy economy and climate change — spans three decades, during which time he published several books, numerous scientific papers and made countless presentations. His most recent book, "Global Energy Technology Strategy, Addressing Climate Change," distills more than a decade of research on the role of technology in addressing climate change. Edmonds has served in the capacity of lead author on every major intergovernmental panel on climate change (IPCC) assessment to date and presently serves on the IPCC Steering Committee on New Integrated Scenarios. He serves on numerous panels and advisory boards related to energy, technology, the economy and climate change. He received his doctorate in the field of economics from Duke University in 1975.

S. Malcolm Gillis, Ph.D., was president of Rice University from 1993 to 2004. He is now University Professor and the Ervin K. Zingler Professor of Economics at Rice University. He spent the first 25 years of his professional life teaching economics and bringing economic analysis to bear on important issues of public policy in nearly 20 countries, ranging from the United States and Canada to Ecuador, Colombia, Ghana and Indonesia. From 1986 to 2004, his career was devoted primarily but not exclusively to university leadership. During that period, he continued to publish in his scholarly specialties. Professor Gillis' research and teaching activities fall into two broad categories: fiscal economics and environmental policy. He has published more than 70 journal and book articles. He is author, co-author or editor of eight books, including the widely acclaimed publications "Public Policies and the Misuse of Forest Resources" (1988) and "Tax Reform in Developing Countries" (1989), as well as the leading textbook in the field, "Economics of Development" (fifth edition, 2002), now available in five languages. Gillis remains active in teaching at Rice University, both in the economics department and the Jesse H. Jones Graduate School of Management.

Robert Harriss, Ph.D., is president and CEO of the Houston Advanced Research Center. He was formerly senior scientist and director of the Institute for the Study of Society and the Environment of the National Center for Atmospheric Research, Boulder, Colo. His current adjunct appointments include professor, department of marine sciences, Texas A&M University at Galveston; and principal scientist, the Institute for Oceans and Coasts. Previous appointments include a Harvard University postdoctoral fellowship and faculty appointments at McMaster University (Canada), Florida State University, the University of New Hampshire, and Texas A&M University. He also served as a senior scientist at the NASA Langley Research Center and as science director of the Mission to Planet Earth Program at NASA Headquarters. Harriss obtained a Bachelor of Science in geology from Florida State University and a doctorate in geochemistry from Rice University.

Peter Hartley, Ph.D., is a Rice scholar of energy economics for the James A. Baker III Institute for Public Policy. He is also the George and Cynthia Mitchell Chair and a professor of economics at Rice University, as well as the academic director of the Shell Center for Sustainability. He has worked for more than 25 years on energy economics issues, focusing originally on electricity, but including also work on gas, oil, coal, nuclear and renewables. He wrote on reform of the electricity supply industry in Australia throughout the 1980s and early 1990s and advised

the government of Victoria, Australia, when it completed the acclaimed privatization and reform of the electricity industry in that state in 1989. The Victorian reforms became the core of the wider deregulation and reform of the electricity and gas industries in Australia. Hartley has published research on theoretical and applied issues in money and banking, business cycles and international finance. In 1974, he completed an honors degree at the Australian National University, majoring in mathematics. He worked for the priorities review staff, and later the economic division, of the prime minister's department in the Australian government while completing a master's degree in economics at the Australian National University in 1977. Hartley earned a doctorate in economics at the University of Chicago in 1980.

John P. Holdren, Ph.D., is the Teresa and John Heinz Professor of Environmental Policy and director of the Program on Science, Technology, and Public Policy at the Kennedy School of Government, Harvard University, as well as director of the Woods Hole Research Center. He is also a professor in Harvard's department of Earth and planetary sciences and the immediate past president of the American Association for the Advancement of Science. His research and engagement with policy have focused on energy technology and policy, causes and consequences of global environmental change, and nuclear nonproliferation and arms control. Trained in space science and plasma physics at the Massachusetts Institute of Technology and Stanford, Holdren co-founded in 1973 and co-led until 1996 the interdisciplinary graduate program in energy and resources at the University of California, Berkeley. He is a member of the National Academy of Sciences, the National Academy of Engineering, and the American Academy of Arts and Sciences.

Amy Myers Jaffe is the Wallace S. Wilson Fellow in Energy Studies at the James A. Baker III Institute for Public Policy and associate director of the Rice University energy program. Her research focuses on the subject of oil geopolitics, strategic energy policy, including energy science policy and energy economics. Jaffe is widely published in academic journals and numerous book volumes and served as co-editor of "Energy in the Caspian Region: Present and Future" (Palgrave, 2002) and "Natural Gas and Geopolitics: From 1970 to 2040" (Cambridge University Press, 2006). She served as a member of the reconstruction and economy working group of the Baker/Hamilton Iraq Study Group and as project director for the Baker Institute/Council on Foreign Relations Task Force on Strategic Energy Policy. She was among *Esquire* magazine's 100 Best and Brightest honorees in the contribution to society category in 2005. Prior to joining the Baker Institute, Jaffe was the senior editor and Middle East analyst for *Petroleum Intelligence Weekly*, a respected oil journal. She received her bachelor's degree in Arabic studies from Princeton University.

The Honorable John Kerry is the United States senator from Massachusetts. For decades in public service, John Kerry has been an environmental leader, fighting on citizens' behalf to clean up toxic waste sites, to keep our air and water clean, and to protect the Arctic National Wildlife Refuge and other pristine wilderness areas. He has just returned from Bali, where he represented the United States at the International Climate Negotiations. Kerry has been called the Senate's most outspoken environmentalist and the League of Conservation Voters has called him an "environmental champion." In 1970 he helped organize Massachusetts' first Earth Day, and then led the fight against acid rain in the Northeast as lieutenant governor of Massachusetts. He helped defeat efforts to roll back the environmental accomplishments of a generation, whether in the form of regulatory reform or efforts to drill in national monuments and the Arctic National Wildlife Refuge. Teaming up with John McCain, he stood up to the powerful Washington interests and led an uphill fight to improve fuel efficiency in automobiles. Having represented the United States at global climate change summits, including Rio de Janeiro and Kyoto and The Hague, Kerry led the Senate's effort to make environmental preservation a global priority through comprehensive treaties and pushing for the inclusion of important environmental protections in free trade agreements. In addition to supporting important environmental initiatives, Kerry has turned a spotlight on powerful Washington interests, their rollbacks of our hard-won environmental gains and their outdated, old-economy notions that clean air, clean water and our national treasures must be sacrificed in the name of short-term profit.

Timothy L. Killeen, Ph.D., is the director of the National Center for Atmospheric Research (NCAR) and a senior scientist at NCAR's High Altitude Observatory. Prior to joining NCAR, Killeen was professor of atmospheric and space sciences at the University of Michigan. During his tenure at Michigan, he also held positions as director of the Space Physics Research Laboratory and associate vice president for research. He is a principal investigator and instrument developer for a space-borne Doppler interferometer on the NASA Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) spacecraft, and co-principal investigator for a new National Science Foundation (NSF) Science and Technology Center devoted to numerical modeling of space weather. He is president of the American Geophysical Union (AGU), a fellow of the American Meteorological Society (AMS), a former AMS councilor, and is a newly elected member of the National Academy of Engineering. Killeen has served as president of the Space Physics Section of the American Geophysical Union, and on numerous NASA, NSF, AGU and university committees. He served as co-chair of the NASA Sun-Solar System Connection Strategic Roadmap Committee, and is a past editor-in-chief of the *Journal of Atmospheric and Solar-Terrestrial Physics*. Killeen received a Bachelor of Science in physics and a doctorate in atomic and molecular physics from the University College, London.

Steven E. Koonin, Ph.D., joined BP p.l.c in 2004 as group chief scientist. He is responsible for the company's long-range technology plans and activities, particularly those "beyond petroleum." He also has purview over BP's major university research programs around the world and provides technical advice to BP's senior executives on matters on Group significance. He joined the California Institute of Technology (Caltech) professorial faculty in 1975, and served as the institute's vice president and provost from 1995 to 2004. Koonin is a fellow of the American Physical Society, the American Association for the Advancement of Science, the American Academy of Arts and Sciences, and a member of the Council on Foreign Relations and the Trilateral Commission. He has served on numerous advisory bodies for the National Science Foundation, the Department of Defense, and the Department of Energy and its various national laboratories. His research interests have included theoretical nuclear, many-body, and computational physics, nuclear astrophysics, and global environmental science. Koonin was born in Brooklyn, New York, and received a Bachelor of Science in physics from Caltech in 1972 and a doctorate in theoretical physics from Massachusetts Institute of Technology in 1975.

Neal Lane, Ph.D., is senior fellow in science and technology policy at the James A. Baker III Institute for Public Policy, and the Malcolm Gillis University Professor and professor in the department of physics and astronomy at Rice University. Prior to returning to Rice University, Lane served in the federal government as assistant to the president for science and technology and director of the White House Office of Science and Technology Policy (OSTP) from 1998 to 2001, and as director of the National Science Foundation (NSF) and member (ex officio) of the National Science Board from 1993 to 1998. Before his post with NSF, Lane was provost and professor of physics at Rice University, a position he had held since 1986. He first came to Rice in 1966, as an assistant professor in the physics department. In 1972, he became professor of physics and space physics and astronomy. He left Rice from 1984 to 1986 to serve as chancellor of the University of Colorado at Colorado Springs. In addition, from 1979 to 1980, while on leave from Rice, he worked at the NSF as director of the division of physics. Lane received his doctorate, Master of Science, and Bachelor of Science in physics from the University of Oklahoma.

Paul Lynch is Her Majesty's consul-general for the British Consulate-General in Houston. Prior to coming to Texas in 2007, Lynch held the same position in Osaka, Japan, while simultaneously serving as commercial consul. From 1996 to 2001, Lynch held two first secretary positions with the British Embassy in Tokyo. He worked in the science and technology division for four years before taking one year to engage in full-time Japanese language study. Upon his return to the workforce, he spent the next year as the first secretary for the commercial division. From 1994 to 1996, Lynch worked as the private secretary to the parliamentary secretary for the Cabinet Office. Ahead of his stint with the Cabinet Office, Lynch worked for the Home Office from 1991 to 1994. While there, he was involved in steering through Parliament the Criminal Justice Act of 1994. In addition to his government posts, he worked for the Monbusho Japanese Exchange and Teaching (JET) program on the Kawaguchi City Board of Education in Saitama Prefecture, Japan, from 1988 until 1990. Lynch received his Master of Science in social psychology from the London School of Economics and his Bachelor of Science in psychology from the Hatfield Polytechnic.

Gilbert E. Metcalf, Ph.D., is a professor of economics at Tufts University and a research associate at the National Bureau of Economic Research. Metcalf has taught at Princeton University and the Kennedy School of Government at Harvard University and has served as a visiting scholar at the Joint Program on the Science and Policy of Global Change at Massachusetts Institute of Technology. He has served as a consultant to various organizations including the Chinese Ministry of Finance, the U.S. Department of the Treasury, and Argonne National Laboratory. Metcalf's primary research area is applied public finance with particular interests in taxation, energy and environmental economics. His current research focuses on policy evaluation and design in the area of energy and climate change. He has published papers in numerous academic journals, has edited two books, and has contributed chapters to several books on tax policy. Metcalf received a Bachelor of Arts in mathematics from Amherst College, a Master in Science in agricultural and resource economics from the University of Massachusetts, Amherst, and a doctorate in economics from Harvard University.

Ernest J. Moniz, Ph.D., is the Cecil and Ida Green Professor of Physics and Engineering Systems, director of the MIT Energy Initiative, and director of the Laboratory for Energy and the Environment at the Massachusetts Institute of Technology (MIT), where he has served on the faculty since 1973. Moniz served as undersecretary of the Department of Energy (DOE) from 1997 until 2001. In that role, he had programmatic oversight responsibility for the offices of science, fossil energy, energy efficiency and renewable energy, nuclear energy, science and technology, environmental management and civilian radioactive waste management. He also led a comprehensive review of the nuclear weapons stockpile stewardship program and served as the secretary's special negotiator for Russia initiatives. Moniz also served from 1995 to 1997 as associate director for science in the office of science and technology policy in the executive office of the president. At MIT, Moniz served as head of the department of physics and as director of the Bates Linear Accelerator Center, a DOE user facility. His principal research contributions have been in theoretical nuclear physics and in energy technology and policy studies. Moniz received a Bachelor of Science in physics from Boston College and a doctorate in theoretical physics from Stanford University.

Scott S. Nyquist is a director in McKinsey & Company's Houston office and a leader in McKinsey's energy practice. He joined McKinsey in 1984 and worked in McKinsey's London office between 1985 and 1998. He transferred from London to Houston in January 1998. He has led McKinsey's European petroleum, Americas petroleum, and Texas energy practices. He now co-leads McKinsey's global energy and materials sector. Nyquist has extensive experience in helping private and public sector clients develop and implement strategies and major change programs that significantly improve their performance. Before joining McKinsey, he worked for Exxon Production Research

in Houston, where he was involved in offshore oil platform design. Nyquist graduated from the University of Michigan with a Bachelor of Science in chemical engineering and obtained a Master of Business Administration from the Harvard Business School.

Emil Peña was named executive director of the Energy & Environmental Systems Institute of Rice University on Oct. 15, 2007. Previously, Peña served in the U.S. Department of Energy (DOE) as the deputy assistant secretary for the Office of Natural Gas and Petroleum Technology, Office of Fossil Energy. In this position, he was responsible for administering oil and gas programs including research and development, planning and environmental analysis, and import and export activities. Prior to his appointment to the DOE in March 2000, Peña was president of Emil T. Peña Interests, Inc., a government affairs company representing clients at the state and local levels. From 1981 to 1985, Peña served as assistant director of public affairs field operations at Atlantic Richfield Company (ARCO), where he represented the company before state and local government bodies in an 11-state region and maintained a working relationship with elected officials as well as industry associations. From 1979 to 1981 at Miller Brewing Company, Peña was the government affairs manager, responsible for representing the company in an eight-state area in the Southwest. At LoVaca Gathering Company from 1977 to 1979, Peña was the community relations and public affairs assistant to the director and vice president for public affairs. Peña holds a Master of Arts in environmental management from The University of Texas, San Antonio, and a Bachelor of Arts in political science, history and sociology from Texas A&I University, Kingsville.

Milo Sjardin is head of New Carbon Finance (NCF) in North America, and is a leading expert on carbon market analysis and price forecasting. In this capacity he is responsible for developing and supporting carbon price modeling tools for the emerging North American markets, leading the analysis for the emerging North American markets, and working with major financial and energy sector organizations to help them understand the implications of the climate change legislation in North America. Prior to this role, Sjardin led the development of NCF's quantitative analysis of the European and global Kyoto carbon markets based out of London, and has assisted numerous companies in assessing future carbon prices and trading strategies. Sjardin has an undergraduate degree in physics and a master's degree in energy and resources from Utrecht University and Imperial College London.

Daniel Sperling, Ph.D., is professor of civil engineering and environmental science and policy, and founding director of the Institute of Transportation Studies at the University of California, Davis (UC Davis). He is also associate director of the UC Davis Energy Efficiency Center. In February 2007, the governor of California appointed Sperling to the California Air Resources Board. He also served as co-director of the California Low Carbon Fuel Standard study. In the past 25 years, he has authored or co-authored more than 200 technical papers and 10 books. He was a lead author of the transportation chapter in the 2007 IPCC report, "Mitigation of Climate Change," and a recent member of 11 National Academies committees on energy efficiency, gasoline taxes, hydrogen, transport in China, biomass fuels research and development, sustainable transportation, and related topics. He was founding chair of standing committees for the U.S. Transportation Research Board on Alternative Transportation Fuels (1989–1996), and Sustainability and Transportation (2006–present). He was selected as a national associate of the National Academies in 2004. Sperling has a doctorate in transportation engineering from the University of California, Berkeley, and Bachelor of Science from Cornell University.

Mort Webster, Ph.D., has been a visiting assistant professor at Massachusetts Institute of Technology (MIT) in the Joint Program on the Science and Policy of Global Change and in the department of Earth, atmosphere and planetary sciences since 2006. From 2001 to 2006, he was an assistant professor of public policy at the University of North Carolina at Chapel Hill. Webster's research program is focused on the role of uncertainty (scientific or otherwise) in policy decisions and in the design of effective environmental policy. At the broadest level, he is interested in exploring the interface between formal quantitative models and the policy process. His work focuses on how to analyze the uncertainty in assessment models of global climate change to produce insights that are useful to the policy community, including addressing the role of learning in the future on today's decision, the effect of uncertainty on multistakeholder negotiations, and better means of communicating results to nonexperts. He received a Ph.D. (2000) in technology, management and policy from MIT and a Bachelor of Science in Engineering (1988) in computer science and engineering from the University of Pennsylvania.

John P. Weyant, Ph.D., is a professor of management science and engineering at Stanford University, where he has been since 1977. He came to Stanford primarily to help develop the Energy Modeling Forum, of which he is director. Weyant was formerly a senior research associate in the department of operations research, a member of the Stanford International Energy Project and a fellow in the U.S.-Northeast Asia Forum on International Policy. He is currently an adviser to the U.S. Department of Energy, Pacific Gas & Electric Company, and the U.S. Environmental Protection Agency. His research is focused on global climate change, energy security, corporate strategy analysis, and Japanese energy policy. He is on the editorial boards of *The Energy Journal* and *Petroleum Management*. His national society memberships include the American Economics Association, Association for Public Policy Analysis and Management, Econometric Society, International Association of Energy Economists, Mathematical Programming Society, ORSA, and TIMS. Weyant received his Bachelor of Science and Master of Science in aerospace engineering and astronautics from Rensselaer Polytechnic Institute (RPI) in 1969 and 1970, followed by a Master of Science in operations research and statistics from RPI in 1971. He obtained his doctorate in management science from the University of California, Berkeley, in 1976 and did a postdoctoral fellowship at Harvard University from 1976 to 1977.

Dimitri Zenghelis heads the Stern Review team at the Office of Climate Change for Her Majesty's (HM) Treasury. Previously, he worked as a senior economist on the "Stern Review on the Economics of Climate Change." Zenghelis was lead author on the costs of mitigation, model analyses and comparisons, "competitiveness" impacts, and a significant contributor to the conceptual, theoretical and ethical framework adopted in analyzing the economics of climate change. He is also the joint-lead in disseminating and presenting the Review post-publication. Since joining HM Treasury in 1999, Zenghelis has provided economic analysis and advice for the British government on European and international economic policy as head of the Economic and Monetary Union Analysis Branch and head of economic forecasting. He has been responsible for the internal and published government macroeconomic forecast using the HM Treasury model and has provided regular briefings to Chancellor Gordon Brown and Prime Minister Tony Blair. Prior to joining HM Treasury, Zenghelis worked as a consultant with Oxford Economic Forecasting, and at the Institute of International Finance, Washington, D.C., on East Asian and Southeast Asia trade and investment flows, and macroeconomic policy. He also worked for Tokai Bank Europe in London. In the early 1990s, Zenghelis was a senior economic advisor for the Liberal Democrats in the House of Commons. His university education was at Bristol University and St. Hugh's College, Oxford University.

Beyond Science:

The Economics and Politics of Responding to Climate Change

Saturday, February 9, 2008

Ken Zweibel is the president of PrimeStar Solar of Golden, Colo., a company founded in June 2006 to develop cadmium telluride thin film photovoltaic (PV) modules for solar energy generation. He worked at Solar Energy Research Institute (SERI) (subsequently, National Renewable Energy Lab (NREL)) in Golden for 27 years on the development of cadmium telluride, copper indium diselenide, and amorphous and thin film silicon photovoltaics. From 1995 to 2006, he was manager of the Thin Film PV Partnership Program, which worked closely with U.S. universities and companies, including First Solar and UniSolar. The Thin Film Partnership shared eight R&D100 Awards with U.S. companies for taking technology from the lab to commercial success. He has published numerous papers and articles, and two books on PV, the most recent being, "Harnessing Solar Power: The PV Challenge." Recently he co-authored the article, "A Grand Plan for Solar Energy," published in *Scientific American*, in January 2008. Besides his involvement with PrimeStar Solar, he is interested in solar policy and solutions to climate change and rising energy prices. Zweibel graduated with a Bachelor of Science in physics from the University of Chicago in 1970.