Reflections on the Science and Policy of Energy and Climate Change
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Thank you very much for inviting me to speak this evening. It was easy for me to select a topic for this lecture because few science-related issues have been as prominent in the media as energy and climate change. One of the important benefits of the extensive media coverage is that the link between the two has become firmly established in the public consciousness, at least I hope it has. If we had only to deal with climate science – and by "we" I mean we as world citizens as well as scientists – our task would be relatively straightforward. But the implications of climate science are profound for society, and we have also to deal with the extremely difficult and not at all straightforward issue of how society should respond to its emerging awareness of climate change and its origins. The problem of what to do is even more vexing for our national leaders, who are faced not only with the same personal choices as their countrymen and women, but also with choices about the broad actions they should take as leaders, with all the intricate political and sociological implications imposed by their unique positions in society.

This audience does not need much reminding about the superficial facts. The energy balance of the Earth – the difference between energy absorbed from the sun and other sources and energy re-emitted back into space – is being affected by human activity. Humans have never been passive actors in Earth's ecosphere, and for thousands of years humans have been altering its landscape and the distribution of its biota. Some of these impacts have been painful, such as the fostering of zoonotic diseases through animal husbandry, the destruction of economically important species through over-hunting or fishing, the loss of productive acreage through poor agricultural practices. We know today that these undesirable side-effects of human activity are not recent phenomena. Inexorable population growth, however, and the accompanying evolution of technology have magnified the potential human impact to global scale. And one particular impact, anthropogenic global climate change, is entirely new.

Global climate change is different in the variety as well as in the reach of its impacts, and the first challenge to science is to estimate what those impacts might be. If we believe there are no impacts, or that they are all positive, then climate change is a normal part of environmental science, with no special claim on society's resources. If we believe substantial negative impacts will occur, then science must rise to two more challenges, namely what can be done to avoid or mitigate the impacts, and given that some negative impacts will occur, what actions can be taken to optimize the quality of life for the affected people. These three challenges – estimating impacts, identifying mitigations, devising adaptations – can be reduced to technical issues to which science

can contribute, at least in principle. Beyond these science questions, however, are matters of subjective judgment, the scale and nature of which are also unprecedented. As we meet here this evening, countries have gathered in Bali to debate among themselves how to balance their national aspirations against their obligations to humanity in general, how to value the certainties of the present against the vagaries of the future, and how to interpret conceptions of justice among peoples against the background of the immense and entirely indifferent machinery of Nature. National leaders are grappling with these issues in a glare of public attention that is as unprecedented as the issues themselves, in a blizzard of opinion and commentary that ranges from science to fantasy, borne instantly to every corner of the globe by the miracle of modern information technology.

As a scientist, I am humbled by the power of the media in this debate. Issues that should be matters of fact are lost in oversimplifications and hyperbole. Issues that are clearly matters of opinion are marketed as scientific certainties. The complexity of the phenomena far exceeds the capacity of conventional public discourse, which is not unusual for scientific matters, but rarely do such matters intrude with such amplitude into the public domain. The visibility of the issue, which is entirely justified by its importance, guarantees that it becomes an object and an instrument of politics. Many scientists have willingly participated in the inevitable simplifications that are conventional in politics, acting from the same desire that motivates us all to have our societies do what we believe to be the right thing. From my perspective, science has lost credibility in this discussion in a subtle way. Critics and advocates all stamp their positions with the brand of science. They all claim that science supports their particular views. The subtext is that science is incapable of distinguishing among their views. The latter is more likely than the former, and the distressing fact is that science is being pressed into an awkward service here, and I know I am not the only scientist uneasy about it.

From the point of view of science, the first of the three challenges is the greatest – the estimation of impacts. We have a reasonably good big-picture understanding of the response of the Earth system to the large scale processes that affect its climate. Some parts of the picture are incomplete – the role of clouds, of aerosols, the behavior of the cryosphere – but we know enough to raise the red flag. Negative impacts are predictable in general, if not in detail, and they appear to be serious enough to warrant action to mitigate them if possible.

At this point I want to make a special appeal regarding the reports of the Intergovernmental Panel on Climate Change. The best summaries of our current state of knowledge are the Technical Reports compiled by the IPCC Working Groups 1 and 2. Recall that the objective of these groups of scientist-volunteers is not to perform new investigations, but to survey and compile the current status of science bearing on climate change and its impacts. After that work is done, smaller groups convene to craft brief summaries of the longer compilations – the famous "Summaries for Policy Makers." A grand summary of summaries wraps up the whole exercise, which for the current cycle was completed in Valencia, Spain just a few weeks ago. The summaries and the negotiations that lead to them get all the publicity, and the media seize on a few striking

features of these overviews that they can use as hooks for their stories. Very few, if indeed any, climate science reporters seem to read the underlying technical reports and reflect their complexity. As scientists, you know that complexity does not imply either chaos or incomprehensibility. Here is my plea: You have the scientific skills and background to read and understand the IPCC technical reports, which are written in an accessible style. If you are interested in climate science, I urge you to go to this primary source and study it and form your own impressions of the status of the field. The Summaries for Policy Makers are by their nature incapable of capturing the richness of the underlying documents. You may already be reading original technical papers in one or more subfields that are represented in the IPCC reports. I do that too, but I cannot read them all, and it is impossible for me to glean an impression of the whole field from individual papers. As in most other fields of science, single papers on climate change rarely illuminate the larger field and hardly ever sway it. Your colleagues who authored the technical reports have done the very important work of surveying the entire literature. I urge you to take advantage of their efforts.

The problem of estimating impacts of climate change is exceptionally difficult because the impacts are location-specific and many are sensitive to natural variations such as the El Niño-Southern Oscillation phenomenon, or ENSO. The ENSO phenomenon affects precipitation distributions in many regions of the globe, but the recent IPCC report concluded that the climate models are not yet capable of assessing the impact of global warming on ENSO. The situation with respect to modeling cloud cover and aerosols is even worse, and these phenomena are clearly important in attempts to forecast regional impacts. Not all impactful changes are so localized. CO_2-driven acidification in the ocean's surface layers is likely broadly distributed, and sea-level rises everywhere whatever its magnitude. But assessing impacts even for these pervasive phenomena requires knowing local conditions. Difficult as it may be, regional forecasting is essential for developing response strategies that typically require actions over long periods of time.

Despite the difficulty of forecasting regional impacts, some strategies are obvious. Populations that are already stressed by flooding, drought, and desertification are clearly vulnerable. Investments in better water management, zoning regulations, and agricultural practices will have an immediate impact on the quality of life for these populations, and they are also an essential part of any climate response strategy. We already know the vulnerable regions and we already know the nature of their vulnerabilities. Every international aid program for sustainable development is automatically part of a long term climate response strategy. Water management and long term agricultural practices in the U.S. are also easy targets for climate response investments.

Keep in mind that anthropogenic climate change is not the only source of risk to vulnerable populations. Population growth, industrialization, global mobility, inadequate public health arrangements, and ineffective governments all multiply the negative impacts of climate change. Serious strategies to cope with climate change must address all these as well as measures to reduce the anthropogenic climate drivers. It is very clear that the mitigation of anthropogenic climate change (primarily by reducing CO_2

emissions) is going to occur too slowly to avoid exacerbation of existing undesirable conditions for vulnerable populations. One of the most important decisions governments must make now is how to balance investments in adaptation versus mitigation of climate change. The tone of current public discourse seems to be biased against adaptation, which is incomprehensible to me (and I hope I have judged the mood incorrectly). Social returns on adaptation investments begin immediately and last indefinitely. Social returns on mitigation investments are likely to be negative in the near term, and produce their positive impacts far in the future. Both, however, are necessary.

Which brings me to the issue of energy. The use of fossil fuels for energy is not the only factor that has led to the dramatic increase of CO_2 in our atmosphere since the beginning of the industrial revolution, but it is the primary factor. You know the science: the carbon from fossil fuels essentially adds to the existing carbon already in the biosphere, and ends up as additional CO_2 in the atmosphere. Atmospheric CO_2 persists for many decades and therefore accumulates to ever greater concentrations. As a greenhouse gas, CO_2 is far less potent than methane or water vapor, but there is a lot of it and it acts indirectly to increase the concentration of water vapor which is the major direct contributor to greenhouse warming. As I already mentioned, our models are not good enough to trace this process in regional detail, but we can trace it well enough to estimate certain global effects, and the size of those effects alarms many scientists.

What to do about this is obvious if you are only concerned about climate change. In the short run you should produce fewer greenhouse gases and increase absorption of those already in the atmosphere. In the long run you should eliminate releases of fossil carbon altogether, or limit releases to an amount much smaller than current values. And you should start doing this immediately because Earth's heat balance is already tilted and some effects of massive CO_2 production are already evident. The current annual release from the world's energy economy, by far the largest contributor to increased atmospheric CO_2, is about 27 billion tons of CO_2 – 40% from coal, 40% from oil, and most of the remaining 20% from natural gas (2005 numbers). Here are some figures to keep in mind: the U.S. consumes more than 20 million barrels of oil *per day*, 60 billion cubic feet of natural gas *per day*, 3 million tons of coal *per day*. This is about a fifth of the world's energy consumption. World-wide, coal accounts for about 45% of electricity production, natural gas about 24%, nuclear about 12%. Oil is used mainly for transportation and as a feedstock for the chemical industry.

These numbers are sobering. Fossil fuels have made modern economies possible. The economic development path is paved with fossil fuels. For any given economy CO_2 production is proportional to Gross Domestic Product. The coefficient of proportionality is sensitive to technology, recently developed or developing economies being significantly more "carbon intensive" than older developed economies. This is good news. It means introducing modern energy technologies in the rapidly developing parts of the world can slow the growth of fossil CO_2 relative to the historical development path. The objective of a CO_2 mitigation strategy should be to reduce the carbon intensity of the world's economy toward zero.

Why shouldn't the goal be simply to reduce the absolute carbon emission toward zero? Why bring in the notion of "intensity?" Because the cause of our climate anxiety in the first place – the root cause – is the overwhelming desire of people everywhere to improve their lot. That desire will not be denied. From all I have ever read or seen of human behavior, the will to better human circumstances must be accommodated in any social plan of action, and especially one designed to persist over decades, perhaps centuries. If we are to make any progress in mitigating anthropogenic climate change, it will be necessary to break the link between economic development and fossil fuel emissions. Simultaneous economic development – *i.e.* growth in GDP – and CO_2 reduction implies reducing carbon intensity. This is a point of the utmost importance in crafting a successful global climate strategy.

The link between GDP and fossil fuel CO_2 emissions is technology. Technology choices in a society, especially pervasive ones like energy technology, are dictated by cost. So what are the prospects for reducing the cost of low-carbon-emission technologies to the point where they will replace high-emission technologies in rapidly developing economies? I phrase the question this way to emphasize that dictating limits on carbon emissions to such a country is a fruitless exercise unless alternative low emission technologies are available. And let us be clear that if we are serious about combating anthropogenic climate change, fossil fuel carbon emissions must be reduced in ALL major economies. It is not enough for only the "old rich" economies of Europe and America and Japan to eliminate their emissions. ALL populous countries must eventually adopt low- or no-carbon energy technologies. This poses a vexing economic conundrum, because adjustments in energy technologies must occur during precisely that epoch in post-cold war history – our epoch – when a major transformation in global patterns of trade, wealth, and economic power is also occurring. Any country that intervenes in its own economy to increase the price of low-cost high-carbon-emitting energy in order to make higher cost lower-emitting technology more competitive, will inevitably put itself at a competitive disadvantage with countries that do not have similar policies. And there will always be dissimilar policies as long as significant differences in standards of living exist among economies around the world.

No realistic response to climate change can ignore the current geo-political preoccupation with economic competition among nations. Our own science communities have identified the “Gathering Storm” of global competitiveness as a major justification for increased funding for innovation-boosting research, and a major cause of concern for weakness in our education system. Concern about competitiveness affects immigration policy, tax policy, and trade policy. And it affects climate policy, not only in the United States but in nearly every other country whose economy is "globalized."

The cost associated with altering the energy technology of a large economy is very large. Economists come to widely different conclusions about the cost, and frankly I do not know how to evaluate the different claims. What I do know is that today – as we speak – very few low-carbon technologies exist that can be expanded to the necessary scale. I can think of only one, nuclear fission, that is sufficiently mature and sufficiently scalable to be a serious contender with low-cost coal plants. In the short term, other

"renewable" energy technologies such as wind and solar may help slow emissions, but we do not have low cost versions of the ancillary technologies of electrical storage and transmission that are needed to scale these up even to their current potential. Biomass looks promising for transportation fuel, but is not yet very effective in reducing CO_2 emissions overall, and is not obviously scalable to the larger electrical power industry. Nuclear power is carbon-free, but the subject of such public concern, justified or not, that its substantial expansion will certainly be delayed for decades.

Nor do we have technologies at hand for ameliorating the carbon emissions of existing fossil fuels. Coal is the one we have to worry about. That is ultimately the cheapest, most ubiquitous source of energy for stationary power generation, and it releases the greatest amount of CO_2 when burned. We do not currently have a scalable technology for carbon sequestration, and I do not see one coming soon. The stunningly large fossil fuel consumption numbers I quoted earlier create barriers for any carbon extraction and sequestration scheme. Any industrial scale process has potential environmental impacts, and there are few greater industrial scales than that of power generation. The sequestration industry would have to be of comparable scale.

It is not my intention to dampen enthusiasm for research on climate-related energy technology. On the contrary, I am optimistic that progress will accelerate now that society has turned its attention to the matter. There is no reason to delay picking the low-hanging fruit of low-carbon technology. We *can* increase the efficiency of cars, and convert them first to run on bio-fuel and later on electricity or hydrogen. We *can* capture the energy of wind when it blows and sun when it shines, and later when we have better batteries we can use such transient sources more effectively. We *can* reduce the energy consumption of lighting, of buildings, of domestic machinery and appliances, and of industrial processes, with existing technology. None of these measures, however, addresses the very large share of emissions from stationary power sources that burn fossil fuels, and particularly coal.

In the long run, the research and development areas that promise the greatest payoff for mitigating climate change are carbon capture and storage from coal-fired power plants, and improvements in the reduction of waste and proliferation risk associated with nuclear facilities. Nuclear fusion remains important, but its commercial feasibility is still unproven. Japan currently outspends every other country on energy R&D – more than $3.5 billion in 2006. The U.S. was second in that year with more than $3 billion. No other country comes close. All the EU25 nations together contribute about $2.7 billion. Most of Japan's energy research is on nuclear power, most of the U.S. budget is for non-nuclear energy sources. There is much to do. Other countries can and should do more.

In view of all these considerations, what constitutes a rational path forward? *First*, every major economy in the world needs to make some kind of commitment to long term emissions reduction. I do not think it is possible to force such a commitment. Each country must conclude that it is ultimately in its best interest to join in at least what has been called an "aspirational goal." Developing nations must be included in this

framework. *Second*, technology development must focus on scalable sources – nuclear and coal, while maintaining progress in other areas such as renewable power and efficient end uses. *Third*, although I have not made a point of this, we need better data and agreement on data definitions and measurements that permit comparisons of energy use not only among countries, but also in different economic sectors within the same country. This is essential to the effectiveness of any international agreement. *Fourth*, we need some sort of international financial framework that takes into account private as well as public investments in energy infrastructure. *Fifth*, much, much more attention needs to be given to adaptation. And finally, increased focus on research in low carbon energy technology in all countries. Most of these points are addressed in President Bush's recent initiative with the major economies of the world to develop a framework of action to create and achieve long term carbon emissions goals.

I finished writing my speech to this point last Friday, and on Saturday morning I opened the Wall Street Journal to find an Op Ed that makes many of the same points I have made in this talk. The authors are Gwyn Prins and Steve Rayner, directors of institutes at the London School of Economics and Political Science, and Oxford University, respectively. I want to establish that I did not copy from their article to prepare this talk. I did, however, copy liberally from White House policy documents and Presidential speeches over the past six years.

Already in 2001 it was clear that a major factor in climate policy had to be a realistic strategy for recruiting large developing economies into an international framework. It was equally clear that climate policy is strongly linked to energy policy, and that the scale of the problem would require a campaign that would have to be maintained over the better part of a century. And it was clear that the already polarized nature of the public discourse was obscuring the scale and nature, not so much of the reality of anthropogenic climate change, but of the societal response that would be required.

An objective reading of President Bush's statements and actions on this subject, beginning with the speech he made on June 11, 2001, just before his departure on his first trip to Europe as President, reveals a much deeper appreciation of these issues than is generally assumed. Here at the end of my remarks I will not lapse into defensiveness, but there is no question that the U.S. has positioned itself to deal more realistically with climate change in all its scientific-sociopolitical-economic complexity than most people realize. The President's program to bring together the nations with the world's largest economies is only the most recent of a long history of initiatives to forge a realistic response to the enormous challenge of climate change. I will append an inventory of those initiatives in the written version of these remarks.

Thank you for inviting me to speak this evening. I look forward to your questions and comments.

Information on Administration climate initiatives.

The most useful consolidated source on Administration climate programs is the Council on Environmental Quality (CEQ) web page on Clean Energy and Climate Change:

http://www.whitehouse.gov/ceq/clean-energy.html#Goal

The testimony of CEQ Chairman James Connaughton before the U.S. House of Representatives Committee on Government Reform, July 20, 2006, is a valuable summary of climate programs with many references and graphics:

http://www.whitehouse.gov/ceq/JLC2006_07_20_House_Govt_Reform_Final_WAc_2.pdf

President Bush's early speeches on climate change are required reading for anyone who wants to understand Administration climate policy:

June 11, 2001: http://www.whitehouse.gov/news/releases/2001/06/20010611-2.html

February 14, 2002: http://www.whitehouse.gov/news/releases/2002/02/20020214-5.html

The President's "Major Economies" initiative is described in his speech of September 28, 2007: http://www.whitehouse.gov/news/releases/2007/09/20070928-2.html

This page includes links to a fact sheet and other briefings on the initiative.