DECISIONMAKING IN THE FACE OF UNCERTAINTY

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The art of decision making under uncertainty has a long history; the science of that activity is still in a rudimentary stage and deserves imaginative thought. We must not be driven to poor choices by emotional convictions. But we must not be deferred from action by rigid ideological beliefs. Thomas Malone, Sigma Xi.

I. INTRODUCTION

Policymakers thrive on uncertainty. The challenge of making educated guesses, balancing costs and benefits, weighing the consequences of action versus inaction lures intelligent, creative people into decisionmaking roles. Scientific uncertainty often serves equally well as sword or shield in the battles over values that actually result in international and national policy. In this paper, I hope to bring a bit of the policymaker's perspective to this meeting. The facts about climate change play a critical role in policymaking—especially to the extent that they narrow the debatable issues. But disagreements over current values (traditional economic values vs. new environmental values) and over issues of equity (global, regional, and intergenerational) inevitably drive the debate.

The issue that brings us together at this conference presents a larger challenge, in a way, than any previously experienced. Human activities are altering the concentration of atmospheric gases that affect the earth's stratospheric ozone shield against solar ultraviolet radiation. These gases are also intimately linked to the earth's long term heat balance. In terms of geological time, these alterations—global warming—are occurring at lightning speed, but in terms of human institutional foresight and concern, the "greenhouse" rate of change is barely visible. We know surprisingly little about Earth's HVAC (heating, ventilating, and air conditioning) system, but know for certain that failure to govern exponentially expanding human activity—particularly energy consumption and population expansion—will ultimately mean an irreversible commitment to climate change on catastrophic levels for major regions of the world.

The challenges to governance are enormous. Governments are simultaneously propelled by centripetal and centrifugal forces. The necessity of

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affecting energy consumption decisions that normally take place at very disaggregate levels forces governments to focus on internal business with an unusually fine level of detail. Conversely, the worldwide cooperation required to understand and cope with global warming forces governments to focus outward on affairs well beyond national boundaries. The question before us at this conference is whether there are technical and policy opportunities to diminish the threat of greenhouse gases and still ensure opportunities for sustained, worldwide economic progress. In the remarks that follow, I will put the greenhouse debate in context to help us better understand the fundamental problems we must address.

II. THE NATURE OF THE CRISIS

SCALE makes the global warming problem unique. Those who govern typically deal with issues that are rife with uncertainties—scientific and otherwise—and they must usually make decisions before receiving all of the facts. But they are rarely called upon to set policies or make decisions that affect as many people, over such a long period of time, as the decisions that lie at the heart of this issue. *Thus, it is essential for our governors to have the technical certainties and uncertainties surrounding climate change spelled out as clearly as possible.*

A. Certainties

Through activities such as producing and burning fossil fuels, deforestation, raising animals and crops, heating, air conditioning, and insulating, mankind releases "greenhouse gases" into the air. These gases are transparent to incoming solar radiation, but opaque to outgoing infrared radiation. This process traps heat and slowly warms the atmosphere, earth, and oceans.

Global atmospheric concentrations of several "greenhouse gases" have risen rapidly over the last 100 years.[1] Some of these gases (carbon dioxide, methane, and nitrous oxide) also occur naturally, but their rapid increase is attributable to human activity. Globally, fossil fuel use—the primary source of CO_2—has nearly quadrupled since 1950.[2] The atmospheric concentration of carbon dioxide is currently increasing about 30 to 100 times faster than

1. Intergovernmental Panel on Climate Change, WMO/U.N. Environment Program, Climate Change: The IPCC Scientific Assessment, fig. 3, at xvi (John T. Houghton, G.J. Jenkins, J.J. Ephramus eds., 1990) [hereinafter "IPCC Scientific Assessment"].

2. T.A. Boden, P. Kanciruk, and M.P. Farrell, Carbon Dioxide Information Analysis Center, U.S. Dep't of Energy, *Trends '90: A Compendium of Data on Global Change* ORNL/CDIAC-36, 89 (1990).

the rate of "natural" fluctuations indicated in the paleoclimatic record.[3] Likewise, the atmospheric concentration of methane is increasing more than 400 times faster than the natural rates of variability.[4] Other greenhouse gases—chlorofluorocarbons ("CFCs") and halons—that did not even exist half a century ago are causing global impacts (e.g., stratospheric ozone destruction).

We know that if greenhouse gas emissions continue to increase under "Business As Usual" scenarios, the earth's average temperature is expected to increase 0.3 °C per decade, or by about 3 °C by the end of the next century.[5] At some uncertain net cost, policy measures could conceivably halve that rate of change, and allow more time for human and natural systems to adapt.[6] We also know that the delay between the time the gases are produced and the time when the climatic and ecological impacts are fully felt is considerable. At any given time we are emitting gases whose warming effects on the atmosphere will not be felt fully for another 20 to 60 years, i.e. we are *committing* ourselves to future warming. History also tells us that considerable delays are involved between the time policy options are identified and implemented, and when selected policies actually make a significant difference. In other words, to effect major, lasting change in greenhouse emissions realistically requires several decades or more of sustained action.

Currently, industrialized countries (including Russia and Eastern Europe) contribute about two-thirds of all greenhouse gas emissions, mostly from fossil fuels that are used to power their highly energy-intensive societies (Figure 1). Projections for the United States[7] and several other industrialized countries[8] suggest that over the next two to three decades a combination of conservation, energy efficiency, and alternative energy schemes will allow developed countries to grow economically while keeping their energy growth minimal or even negative at little or no net economic penalty. Positive environmental impacts independent of CO_2 changes will also follow.

Because of their technological sophistication and low population growth, there may be, given time, ample opportunity for industrialized countries to stabilize or even decrease their annual emissions of greenhouse gases.

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3. J.M. Barnola, et al., *Vostok Ice Core Provides 160,000-year Record of Atmospheric CO_2*, 329 Nature 408 (1987). *See also* C. Lorius, et al., *The Ice-Core Record: Climate Sensitivity and Future Greenhouse Warming*, 347 Nature 139 (1990).

4. J. Chappellez, et al., *Ice-Core Record of Atmospheric Methane Over the Past 160,000 Years*, 345 Nature 127 (1990), and IPCC Scientific Assessment, *supra* note 1, at 18-23.

5. Chappellez et al., *supra* note 4.

6. *Id.*

7. *See* Office of Technology Assessment, U.S. Congress, *Changing by Degrees: Steps to Reduce Greenhouse Gases* OTA-O-482 (1991) [hereinafter *"Changing by Degrees"*]; Comm. on Sci., Eng'g and Public Pol'y, Nat'l Academy of Sci., Policy Implications of Greenhouse Warming—Synthesis Panel (1991).

8. Carbon Emissions Control Strategies: Case Studies in International Cooperation (W.U. Chandler ed., 1990).

However, greenhouse gas emissions will surely rise for developing nations still rapidly growing in population and building industrial bases. Developing countries are just beginning to supply electricity to their people, and only starting to use modern methods for cooking, heating, and transportation. Developing countries currently contribute one-third of the global greenhouse gas increase, but each year they are increasing their share.[9] Presently, their emissions come mostly from land use changes and practices (e.g., carbon dioxide from tropical deforestation, and methane from rice cultivation and livestock). Energy projections made for developing countries must recognize that efficiency investments, while crucial to growth, will only decrease the amount of new power needed, but cannot eliminate it.

Figure 2 shows the great disparity in per-capita energy use in different parts of the world. Although a person in a developing country uses about one-fifteenth the amount of energy as the average U.S. citizen, even modest gains in per-capita and total economic growth in these countries translates into emissions that will collectively exceed those from the developed world within a few decades. Developing countries have been increasing their total energy use by approximately 6% per year, in contrast to a 1% increase in OECD countries. They also increased their *electrical* power consumption by an average of 8 percent per year between 1971 and 1987. Most of the added electrical capacity was provided by conventional power plants (which are high CO_2 emitters) for manufacturing and use in buildings. Further increases in electricity generation will be needed since many countries are continuing to electrify as refrigeration and air-conditioning are becoming more widely available, due partly to falling relative price. Without question, rapid population growth, in combination with economic growth, will continue to fuel increased demands for energy and land resources over the next few decades and cause major emissions increases (see Figure 3).

Some global warming seems inevitable, according to a strong consensus that has developed among those researchers closest to the issue. For example, the recent report from the Inter-Governmental Panel on Climate Change, produced by scientists of various disciplines from 25 countries, suggests that a 50%-80% reduction in *current* CO_2 emissions, as well as significant reductions in the other greenhouse gases, are required simply to keep the atmosphere at its already perturbed levels. That extraordinary level of reduction would require the world to rapidly wean itself from fossil fuels. The bulk of the reductions would fall on the *developed* world if the *developing* world is to increase greenhouse emissions, as it must, to feed population growth and raise standards of living. Ultimately, new technologies using solar and/or nuclear energy must replace fossil fuels if the world hopes to keep emissions from growing steeply response to the population doubling

9. Office of Pol'y, Planning and Evaluation, EPA, Policy Options for Stabilizing Global Climate, Draft Report to Congress ch. 9, 5-7 (Daniel A. Lashof and Dennis A. Tirpak eds., 1989).

again, coupled with the corresponding economic growth. In the interim, shifts from carbon-rich fuels (coal) to hydrogen-rich fuels (natural gas) will help.

The fact that most of the actions that can be taken to reduce greenhouse gases are helpful and desirable in other ways as well, should greatly facilitate policy making. Strategies that reduce greenhouse gases generally have ancillary environmental benefits including reducing acid rain, urban smog, groundwater contamination, and waste disposal. Developing and producing renewable energy technologies can strengthen trade markets and international competitiveness. In the United States, the time is especially ripe for a sustained increase in our currently modest efforts to mine the considerable resource of energy efficiency still possible in virtually all sectors of the economy. We must also enhance our ability to develop renewable energy resources. Worries over the negative impacts (on the Nation's trade balance) of increasing the level of oil imports, our national security interests connected with oil production in the Middle East, and the need for industrial innovation to restore U.S. competitiveness in world markets, are all addressed by accelerating the commercial development of nonfossil energy supplies and conservation technologies.

We can learn many lessons from the experience of past energy crises although policies implemented then were focussed primarily on cutting U.S. dependence on oil rather than on all fossil fuels. The energy intensity (energy consumed per unit of GNP produced) of the United States dropped significantly (by about one-third; see Figure 4) between 1973 and 1985. This widely touted flattening of energy consumption, while the GNP grew 35 percent, was mostly due to increases in energy efficiency (the rest came from changes in the make-up of the GNP). But for the most part, investments in energy efficiency occurred when fuel was expensive, when public policies supported such actions, and when the payback for such an investment could be realized quickly. The energy crises of the 1970s taught us that price is a powerful signal, and that there are also surrogates to price (e.g., regulations, taxes, standards, threat of shortages). Signals to affect the energy system of production and use, however, need to be consistent and reinforcing; it is destabilizing to let policy goals get very far away from price-equivalence (e.g., expensive synfuels production failed when fuel prices failed to rise). The pace of permanent change in energy use corresponds to turnover of capital equipment and therefore is measured in decades. Thus government policies need to track such a time schedule; *policies to mitigate global warming must be long-lived and sustained.*

B. Uncertainties

The major uncertainties that remain in the science of climate change are: 1) regional effects; 2) timing of effects; and 3) severity of effects. The available General Circulation Models are not equipped to handle spatial detail and currently give conflicting pictures of climate change for less than continent-sized areas of the globe. Therefore, we cannot expect science to provide guidance for regional "adaptation" strategies (the domain of most public policies) in the near future.

Timing of decision-making and action regarding global warming is more of a policy issue than a scientific one because by the time any effects are discernible (another decade or two for a clear temperature signal), we will have committed ourselves to very substantial effects farther down the road. It could, therefore, be exceedingly helpful to policy makers if science could provide ways of detecting evidence of climate change that are sufficiently convincing to sustain political support. Finally, the potential severity of the greenhouse effect still weighs heavily upon the minds of thoughtful people. Whether the perturbations from human activities might lead to major unanticipated responses in regional or global climate remains an important question. There is ample evidence that the planet's climate has, in times past, shifted suddenly and rapidly. How certain are we that our actions might not trigger unexpected and unhappy consequences from seemingly minor instabilities? Despite our propensity to expect nature to inherently provide negative feedback to man's foibles, we should not count on it. For example, recent observations in the northern hemisphere of stratospheric ozone depletion show that the actual effect of CFCs and other gases is much worse than was predicted by our "best" models.

III. DEFINING AND ATTACKING THE PROBLEM

While a much more detailed understanding of the greenhouse effect provides interesting and critical questions for science, it is not the stuff of which most policy is made. The most interesting and critical question for policy is how governments can react, individually and collectively, to the fact that ultimately the amount of greenhouse gas ("GG") is related to a product of three terms:

GG	=	(GG/GNP) x (GNP/P) x (P), where:
GG	=	greenhouse gas
GNP	=	gross national product (or, preferably, some better measure of delivered goods, services, and amenities)
P	=	number of people

Clearly, from one family, region, or nation to another the different GG factors vary a great deal. For example, in some countries P is large but GNP/P is small. Thus, in working out global strategies one clearly needs to take into account the local situations. If technology were perfect, one could follow a collection of strategies to reduce the first term (GG/GNP) close to zero, theoretically enabling continued expansion of standard of living and/or population without serious GG consequences.

"GG/GNP" is the *technology/marketbasket* term. It has attracted most of our attention in thinking about how to cut the risk of climate change. It lies close to the realm of certainties, for we know that it can be reduced (over decades) by: 1) switching to greater dependence on methane and non-fossil fuels; 2) increasing efficiency of both energy and materials use; 3) halting deforestation by reforesting, and by changing agriculture; and 4) shifting our consumer marketbasket to one that is less energy intensive. Whether we can muster the political will to make these changes is an uncertainty that is highly dependent on strong leadership and technology development.

"GNP/P" is the *goods and services* term. It represents the per-capita standard of living. Governors and the governed balk, rightly, at any suggestion that this term be reduced. International efforts are aimed, again rightly, at increasing this term for as much of the global population as possible. The *population* growth term, "P", is fundamental and its future size is subject to great uncertainty. Over the past several decades, many Lesser Developed Countries ("LDCs") have made important progress in slowing birth rates. This has significantly improved maternal health as well as per-capita economic growth. But even in the face of this progress, the *world population now grows at an all-time record net rate of 10,000 people per hour*, or the population of Mexico every year, with more than 90 percent of that increase occurring in the LDCs (see Figure 5).

The reason for continuing high rates of population growth despite declining birth rates is population "momentum" or the continued growth of a population in absolute numbers for many decades even when couples have only as many children as are needed to replace themselves, or about 2-2.5 children per couple.[10] Population momentum occurs when populations contain a large proportion of young people so that most people are in or entering the reproductive years. Then, the population will continue to grow even with replacement levels of fertility until the population becomes evenly distributed among all age groups. Africa illustrates this point (see figure 6). If birthrates in Africa fell until it attained replacement level fertility by 2030, its population would continue to increase until a stable population of about 1.4 billion is reached. If, however, replacement level is not attained until 2065, just 35 years later, Africa's population would rise to more than three times that number and level off at 4.4 billion. Thus, even a short delay in the date at which replacement rates are reached causes a dramatically different outcome in terms of total population.

On the other hand, sudden, very large decreases in fertility can also have undesirable consequences. China realized this after it instituted its one child

10. Population Reference Bureau, 1990 World Population Date Sheet (1990).

family policy. Strict adherence to the policy would reduce China's population from its current 1.1 billion to about 700 million people by 2050. However, at that time, about 40 percent of the population would be at least 65 years old, a proportion considerably larger than the working population would likely be willing to support.[11] This realization has led to some easing of the one child family policy in China.

Different standards of living and technological sophistication alter the impact of population increases in different countries on GG additions by as much as a factor of 10. A small population growth rate in a very affluent society like the United States can increase GG by as much or more than a large population growth rate in a very poor society—*unless* the affluent society's technological sophistication enables it to, for example, sustain its growth while avoiding fossil fuels.

One hopes and trusts that people in the LDCs will grow more wealthy and that GG additions per person will ultimately stabilize around the planet. Under those conditions, the imperfections of technology and population size are the sole drivers of changes in GG and associated risks. Thus, population stabilization—at home and abroad—is an absolutely essential ingredient in any comprehensive pursuit of protecting global climate.

IV. SHOULD THE UNITED STATES TAKE THE LEAD?

Before I make suggestions for what government could do in response to global warming, let me review some arguments as to why the United States should take the lead. Even though climate change is a "global" problem of sustainable development, leadership by the United States carries several benefits, including:

- Many of the policies to avert global warming *are of merit in themselves for economic, energy security, or environmental reasons*—the so called "no regrets" policies.
- Unilateral action, at least to the extent of "no regrets" initiatives, would indicate the seriousness with which the United States, the largest single contributor to greenhouse emissions, views the problem and would *help to generate a political environment conducive to full international participation.*

And reasons abound for the United States to foster reduced emissions abroad, including:

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11. Thomas W. Merrick with PRB Staff, World Population in Transition, 42(2) Population Bulletin 42 (1988).

- Climate change is a global challenge. While the industrialization that has occurred over the past century is the main culprit for changes in greenhouse gas concentrations to date, industrialization over the next 25 years may have an even greater effect. The effects of climate change will be felt globally, and every country has an interest in the problems associated with the issue. Solutions must come from long-term participation and cooperation by all emitters, as the reductions by any one country—even the United States—will only make a small dent in total greenhouse gas emissions.

- Greenhouse gas emissions will certainly increase in the less developed countries and may rise in the Eastern Bloc and Russia. The less developed countries have higher growth rates for energy use, population, and GNP than industrialized countries. All of these indicators suggest that emissions of greenhouse gases will continue to rise significantly in these countries, just as they have been rising faster than anywhere else in the world. While the industrialized world is talking of stabilizing or even reducing greenhouse gas emissions, general consensus says that a similar goal for developing countries would be next to impossible to achieve.

- Improvements in GG/P may be cheaper and more effective in less developed countries, Eastern Europe, and Russia. Energy use in all of their economic sectors (industry, transportation, agriculture, and residential/commercial) is relatively inefficient when compared to industrialized countries. Therefore, efficiency gains may be greater and less expensive than in an OECD country. Also, much of the energy production and consumption infrastructure is yet to be built in developing countries; they can take advantage of new technologies that may be cost-effective for new construction, but expensive to retrofit.

- Many non-OECD countries lack sufficient internal capital to meet development needs. Large foreign debts coupled with the fact that state-of the-art, efficient equipment generally has higher first costs have led many poorer countries to adopt policies that favor short-term over long-term benefits. Tropical deforestation is but one result of such policies. Lack of capital is often the motivating force behind unsustainable policies; the United States and other aid-giving countries and institutions could make capital conditionally available and help countries adopt longer term sustainable development policies.

- Infrastructure investment that is undertaken now will have a long-term effect on global warming. Many developing countries will dramatically increase their energy and other infrastructure systems over the next twenty-five years. Decisions they make now will likely have important long-term effects. China, for example, has expressed great interest in exploiting its vast coal deposits. Decisions made within the next five to ten years about how coal will be used will impact China's share of greenhouse gas emissions for decades to come.

V. WHAT CAN WE DO?

The major options available or likely to be available for reducing CO_2 emissions in the near-term fall into three categories:

1. Increasing energy conversion efficiency in end-use technologies;
2. Changing patterns of energy consumption; and
3. Shifting energy supply away from high CO_2 emitting fuels.

Decisionmakers may choose from policies which comprise two interdependent components: the universe of possible technical (or in some cases, behavioral) changes and the policy instruments available (e.g., taxes, regulations, financial incentives) to require or encourage the technical change. There are a large number of technical options to pick from and many targets of opportunity within each economic sector (see Figure 7). For effective reduction in CO_2 emissions, these options must be pursued simultaneously through a variety of policy instruments implemented at various levels of government.

For decades, most people have assumed that a single technical option—fossil fuels—would supply human energy needs for another two or more centuries.[12] The rising specter of air pollution and climate change casts an ominous shadow over the already troubled fossil option. In other words, the fossil era may need to end in less than a century. This means that solar and nuclear power (fission and fusion) may be the energy sources for mankind that will be globally dominant, perhaps within fifty years. Unfortunately, for different reasons, neither nuclear nor solar power are attractive options in their present state.

Our only serious technological "bet-hedging" to fossil fuels has taken the form of work on harness nuclear power—fission and fusion. While the latter goal remains frustrating and elusive, the former now accounts for 20% of U.S. electricity, or about 8% of the U.S. total primary energy budget.[13] Other non-fossil fuel (mostly hydroelectric and biomass) adds another 8%. Our present non-fossil energy budget is thus about 16%. But the nuclear fission

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12. U.S. Dep't of Energy, Annual Energy Outlook (1990).

13. John H. Gibbons & Peter D. Blair, *U.S. Energy Transition: On Getting from Here to There*, Physics Today, July 1991, at 22, 28.

enterprise, for several reasons, is in deep trouble — so deep that the requirement to rescue it could well be more difficult than the original task of creating it. Additionally, our commitments to more effectively and broadly harnessing renewable energy sources have been comparatively minimal.

Developing and preserving attractive nuclear and renewable options is certainly possible. For example, photovoltaic conversion efficiency gains have resulted in half an order of magnitude reduction in installed costs.[14] Additional gains are promising; wind turbines are now directly competitive in large areas; and aeroderivative turbines (driven with biomass fuels) and solar thermal technology are nearing direct economic competitiveness.[15] Despite the gains to date, such options require—and merit—long-term commitments of research, development, and investment which, in turn, means we must move ahead on that odyssey now. One candidate goal for U.S. energy policy would be to reduce the carbon intensity of energy use (i.e., net carbon released to the atmosphere per unit of energy delivered) on average by perhaps 5 to 10 percent per decade for at least the next two decades.[16] This goal could be achieved in part by energy conversion efficiency improvements and changing the fuel mix by replacing (and mixing) coal use with natural gas, as well as increasing the use of renewables and nuclear power. The number chosen for this goal is perhaps less important than the will to define a goal and vigorously pursue it. Increased use of natural gas and greater system efficiency would dominate the first decade or two, securing time to allow non-fossil alternative transportation fuels and sources for electric power generation to develop systematically and efficiently. Technologies that would flow from such a commitment could position the U.S. advantageously in terms of future economic competitiveness.

The continuing turmoil and instability in the Middle East has focussed attention once again on energy security concerns and, in particular, on strategies for reducing U.S. dependence on imported oil. Figure 8 sketches the possible impacts—in size and timing—of several aggressive import reduction strategies in supply, efficiency, and fuel shifting. The options include improving automotive fuel economy, increasing domestic produc-

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14. Office of Technology Assessment, U.S. Congress, Energy Technology Choices: Shaping Our Future OTA-E-493, at 98 (1991).

15. *Id.* at 92-101.

16. OTA's analysis shows that a decrease of 5-10 percent per decade would be technically feasible but "tough." For Changing by Degrees, OTA developed a "moderate" emissions reduction scenario (which could be achieved at a net savings but would require substantial shifts in the economy) that could freeze carbon emissions until 2005 and also developed a "tough" scenario (technically possible but entailing costs in excess of projected fuel savings) that would reduce carbon emissions by 20 percent below expected levels by 2005. An emissions reduction of 5-10 percent per decade brackets the "tough" scenario. *See Changing by Degrees*, *supra* note 7.

tion of oil, switching to alternative fuels in transportation, and a mix of fuel-switching and improved efficiency steps in industry and the residential and commercial sectors.

As can be seen from Figure 8, vigorous and sustained efforts are required to limit oil import dependence over the next several decades—even to a level of 50%. The largest and most attractive opportunities lie on the demand side. Fortunately, these efforts can provide good jobs and important new economic activity and strength at home. To the extent that we improve efficiency cost-effectively, supplies last longer, economic competitiveness improves, the balance of payments drops, environmental problems are eased, and international tensions are lessened. But improved efficiency, however dramatic, is not enough. The traditional opportunities on the supply side, such as enhanced domestic production in the lower 48 states, offshore and in Alaska, are more modest than increased demand efficiency, but still important. And there are various opportunities for shifting over time to alternative transportation fuels such as methanol, CNG, electricity, and others. However, these fuels have extensive long-term implications. The oil replacement potential must be weighed against the energy and environmental costs associated with producing and using these fuels.[17]

The *pacing* of all the efforts described above is an essential feature. Like making a turn in a fully loaded supertanker, change in the energy system must be given time if it is to be non-violent. Patterns of energy supply or demand can change radically as technology changes and capital stock turns over, but we have learned that short-term changes or policy and technology "quick-fixes" can readily lead to economic hardship and inefficiency.

What should the U.S. government do? Several opportunities offer benefits with minimal risks, including:

- The government could invest in achieving a greater understanding of what is happening to the Earth, in devising ways to achieve sustainability, and also in fostering mechanisms to facilitate more conservative approaches to greenhouse warming. We need more research, modeling, and scenario development on the source, action, and fate of greenhouse gases, on technologies for energy supply and demand, and on social and technological means to hasten population stabilization.
- As part of the international community, the government could acquire the expertise to develop and sort out our most attractive options for both mitigation and adaptation. Technology offers extraordinary opportunities, but greater innovation, based on international cooperation, will be required. For example, analogous to U.S. air quality

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17. *See generally* Office of Technology Assessment, U.S. Congress, Replacing Gasoline: Alternative Fuels for Light-Duty Vehicles OTA-E-364, at ch. 3 (1990).

strategies, we could consider the concept of "global bubbles" for least-cost greenhouse gas reduction. If it is less costly to trap CO_2 in the tropics than in the temperate zone, what could be done to take advantage of that fact?

- The government could set some measurable, sensible goals beyond CFC regulation, e.g., on energy consumption levels, or efficiency improvement levels, or gains in nonfossil supplies, for the near term (next 10 years) and the long term (next 50 years). This would define the path we will follow as a nation and could help us get past the doldrums of drifting along energy paths that lead to more dependence on imports from insecure sources, increased greenhouse emissions, and loss of global leadership in making a major energy transition in the coming decades.

- For more than a decade, U.S. policy on population growth and family planning assistance has been counter-productive to the goal of rapid achievement of population equilibrium. U.S. refusal to support the U.N. Population Office, policies that block research on contraception and discourage U.S. production of contraceptives, and policies to cut teen pregnancies need to be reexamined in light of the crucial role that population stabilization will play in reducing greenhouse gas emissions. Where appropriate, these policies should be reversed or revised. The unmet need for family planning services is tremendous in much of the world and represents a policy arena in which the United States could make an important contribution. In addition, research and education in contraception and demographics could be boosted substantially.

- Many traditional public policies that bias actions toward higher resource consumption need to be fixed. We still measure economic progress in terms of how fast raw materials flow through our economic system. We generally remain hooked on the notion that exponential expansion is a favored route to salvation, even though that paradigm is woefully out of date. We must develop a better appreciation of the need to think in terms of S-curves rather than exponentials (see Figure 9).

The United States is ideally positioned to lead a global effort to both minimize and adapt to climate change and help change exponentials into S-curves so that sustainable development can become a reality. We are technically sophisticated; we are open and innovative; and we presently use a major portion of the world's resources. Confronted by the harsh reality of resource finiteness, we should recognize and respond to the good news of our enormous potential to provide the means for progress through thoughtful use of technology.

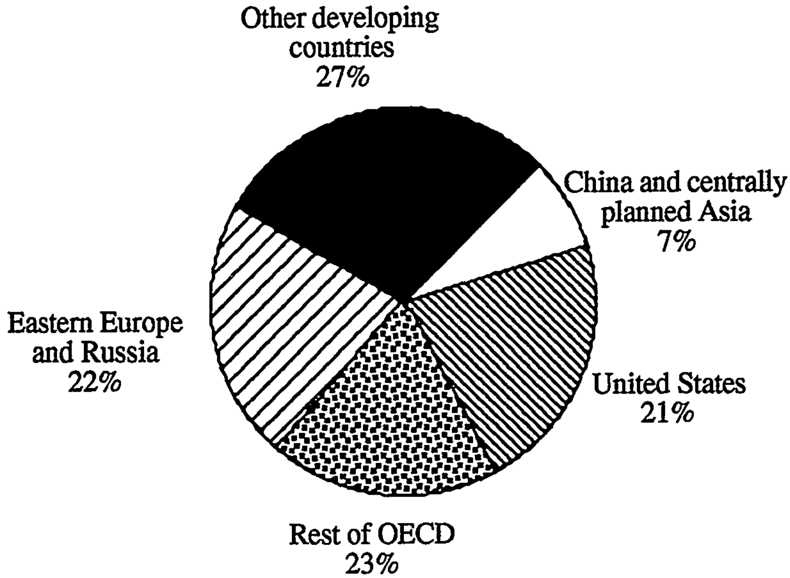
VI. SUMMARY

Public policy-making is frequently done in an environment of technical uncertainty. Other factors, such as public opinion, special interest pressures, and fear of alternatives generally dominate. The defense budget is full of enormous commitments to counter threats that are arguably much less certain—or damaging— than global climate change.

Public policy is a *process*, not an event. It is usually iterative and adaptive, making "uncertainty" less important that it might be otherwise.

Policy decision-making with respect to global climate must compete with other priorities. The fact that effective climate policies must include market interventions, lifestyle changes, long time commitments, and widespread participation from local and international bodies doesn't make the challenge any easier. Fortunately, the vast bulk of actions that can be taken to thwart global climate change are also helpful in achieving other goals such as sustainable development, environmental quality, the *inevitable* transition beyond fossil fuels for energy supply, and international economic and military security.

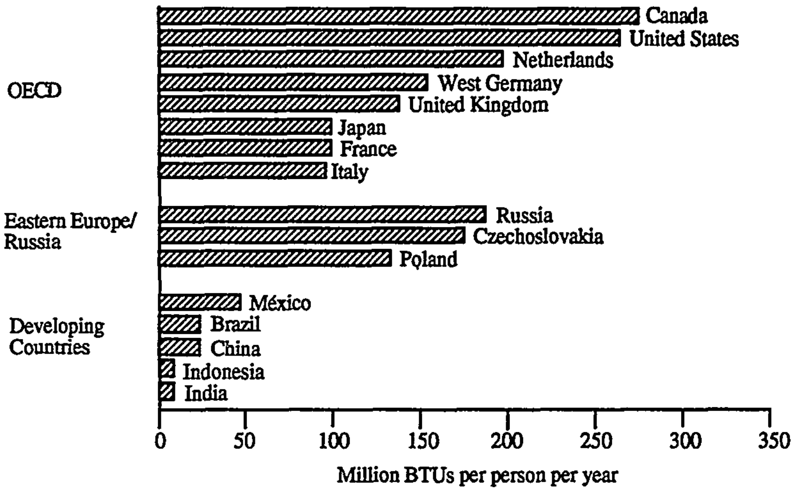
Figure 1. Greenhouse Gas Emissions in 1985 by Region



NOTE: Figure shows the share of greenhouse gas emissions by region, weighted by their contribution to radiative forcing between 1980 and 1990. It includes all greenhouse gases and CO_2 from deforestation and fossil fuel use. Estimates for CO_2 emissions from deforestation range from less than 10 to about 30 percent to total CO_2. If the upper range proves to be correct, developing countries' shares would be larger.

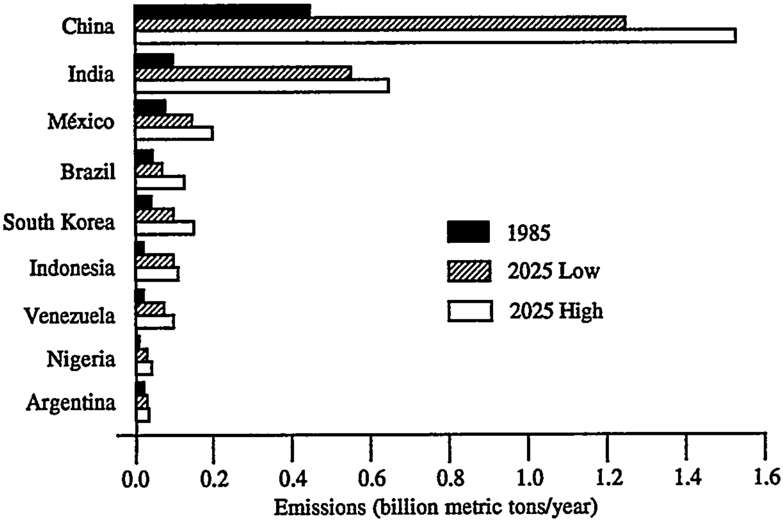
SOURCE: Adapted from U.S. Environmental Protection Agency, 1990.

Figure 2. Per Capita Energy Consumption



SOURCE: U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries*, OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991).

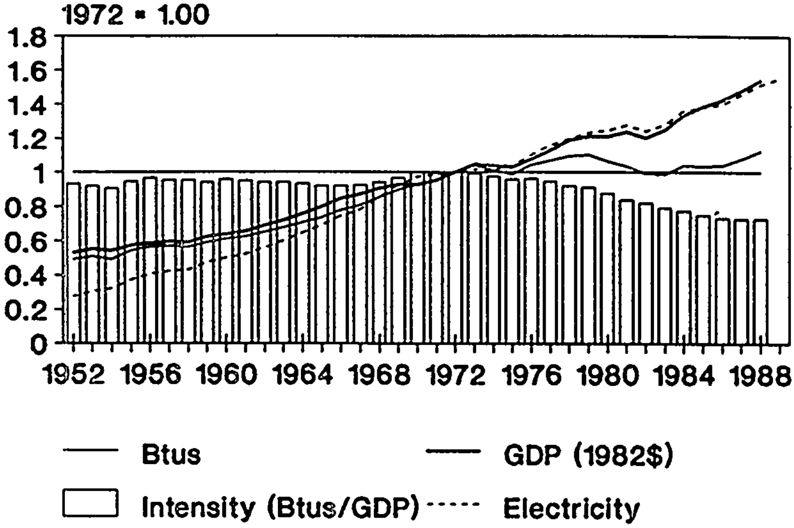
Figure 3. Projected CO_2 Emissions in Selected Developing Countries (including use of biomass).



CO_2 emissions in developing countries are projected to rise significantly by 2025, as shown here for four countries in Asia, four in Latin America, and one in Africa. The "High" scenario assumed no constraints on economic and energy growth. The "Low" scenario assumed that policies are enacted to improve energy efficiency and change the fuel mix.

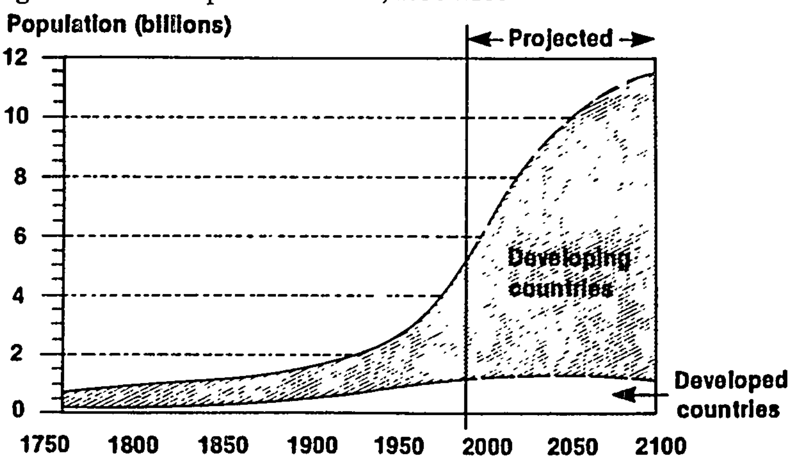
SOURCE: J. Sathaye and A. Ketoff, *CO_2 Emissions From Major Developing Countries: Better Understanding the Role of Energy in the Long Term*, Interim Report, LBL-29507 (Berkeley, CA: Lawrence Livermore Laboratory, August 1990).

Figure 4. Index of U.S. GDP, Energy Intensity, Energy Use, and Electricity Use



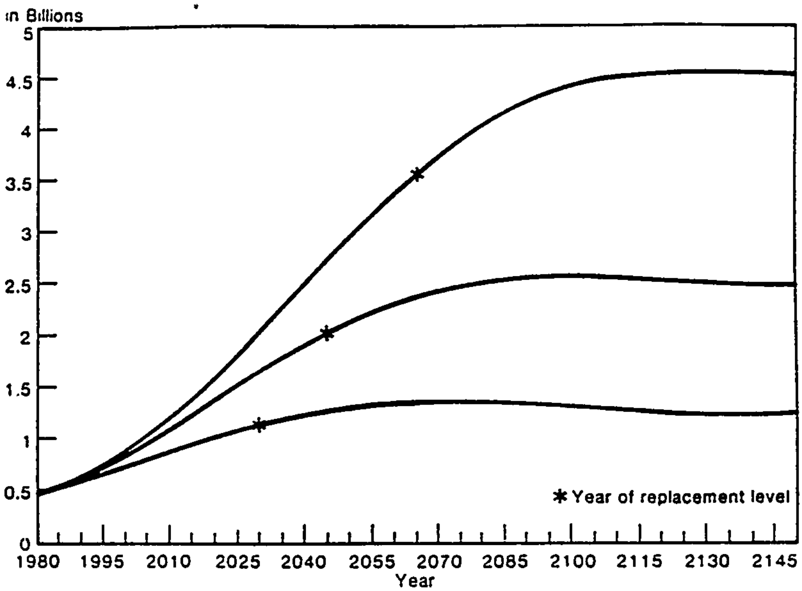
SOURCE: U.S. Energy Information Administration, Monthly Energy Review, March 1991, DOE/EIA-0035(91-03) (Washington DC: U.S. Government Printing Office, Mar. 28, 1991).

Figure 5. World Population Growth, 1750-2100



SOURCE: Thomas W. Merrick with PRB Staff "World Population in Transition," *Population Bulletin*, Volume 41, No. 2, Pg. 4, January 1988 Reprint, update by Carl Haub, Population Reference Bureau, 1991.

Figure 6. Population Momentum in Africa



When a country reaches replacement-level fertility, it might be expected that the population growth rate would immediately reach zero. However, if the decrease to replacement is comparatively rapid, the large proportion of younger persons in the population will cause growth to continue for some time. In the above UN projections for Africa, note that in all three variants the population continues to grow after repacement is reached.

SOURCE: Carl Haub, "Understanding Population Projections," *Population Bulletin,* Vol. 42, No. 4, p. 28, December 1987.

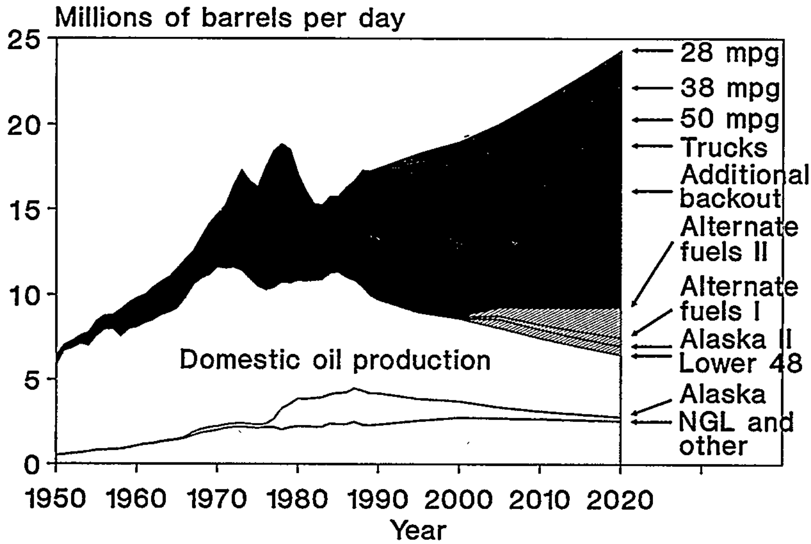
Figure 7. Policy Instruments To Reduce CO_2

	Taxes			Financial incentives			Marketable permits	Regulations		RD & D		Information	
	Energy tax	Carbon tax	Purchase tax	Tax incentive	Low cost loans	Direct payments		Performance standards	Building codes	R&D	Demonstration	Labels/ rating	Audits
Commercial buildings													
Thermal integrity	✓	✓	—	✓	✓	✓	—	—	✓	✓	✓	✓	✓
Appliance/lighting	✓	✓	✓	✓	—	✓	—	✓	—	✓	—	✓	✓
Usage patterns	✓	✓	—	—	—	—	—	—	—	—	—	—	✓
Residential buildings													
Thermal integrity	✓	✓	—	✓	✓	✓	—	—	✓	✓	✓	✓	✓
Appliance/lighting	✓	✓	✓	✓	✓	✓	—	✓	—	—	—	✓	✓
Usage patterns	✓	✓	—	—	—	—	—	—	—	—	—	—	✓
Transportation													
Small car/truck efficiency	✓	✓	✓	✓	✓	✓	—	✓	—	✓	✓	✓	—
Alternate fuels	—	✓	—	✓	✓	✓	—	—	—	✓	✓	—	—
Off highway[a]	✓	✓	—	—	—	—	—	✓	✓	—	—	—	—
Vehicle miles traveled	✓	✓	—	—	—	—	—	—	—	—	—	—	—
Manufacturing													
Efficiency	✓	✓	—	—	—	—	✓	—	✓	✓	—	—	—
Recycling	✓	✓	—	✓	—	✓	—	—	—	—	—	—	✓
Energy supply													
High to low carbon fuels	—	✓	—	—	—	—	✓	—	—	✓	✓	—	—
Renewable	✓	✓	—	✓	—	✓	✓	—	✓	✓	—	—	—
Cogeneration	✓	✓	—	✓	—	—	✓	—	—	—	—	—	—
Efficiency, existing plants	✓	✓	—	—	—	—	✓	—	—	—	—	—	✓
Forests													
Recycling	—	—	—	✓	—	✓	—	✓	—	—	—	✓	—
Increased productivity	—	✓	—	✓	—	✓	—	—	—	✓	—	—	—
Afforestation	—	✓	—	✓	—	✓	—	—	—	—	—	—	—
Biomass	✓	✓	—	✓	—	—	—	—	✓	✓	—	—	
Food													
Farm inputs	—	✓	—	—	—	✓	—	✓	—	—	✓	✓	✓
Farm operation & efficiency	—	✓	—	✓	—	✓	—	✓	—	✓	—	—	—
Food processing	—	✓	—	—	—	—	—	—	✓	—	✓	—	✓

[a]Heavy equipment, aircraft.

SOURCE: Office of Technology Assessment, 1991.
Report on Changing by Degrees: Steps to Reduce Greenhouse Gases.

Figure 8(1). U.S. Oil Supply and Demand Futures
Baseline Porjection: Current Trends in Domestic Oil Production, Net Imports, and 1989 New Car Fuel Economy



SOURCE: Office of Technology Assessment 1991.

Figure 8(2). U.S. Oil Supply and Demand Futures
Improved Supply, Mileage, and Backout

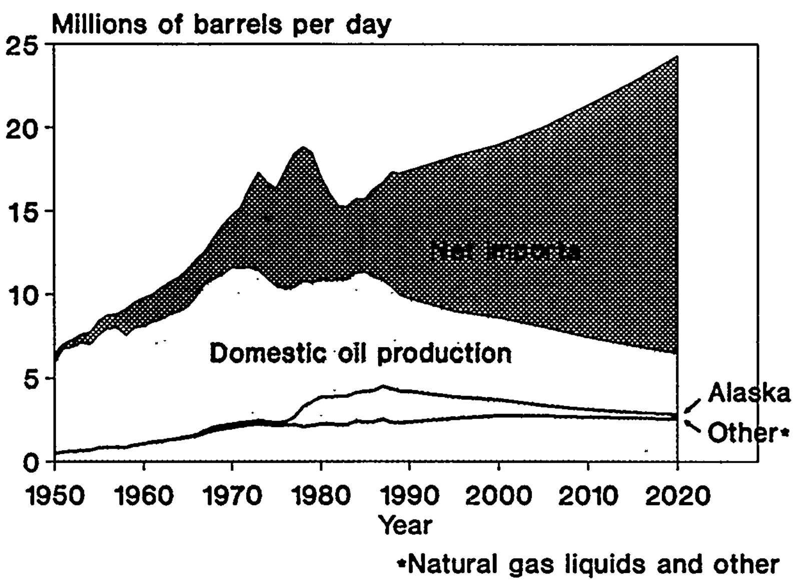
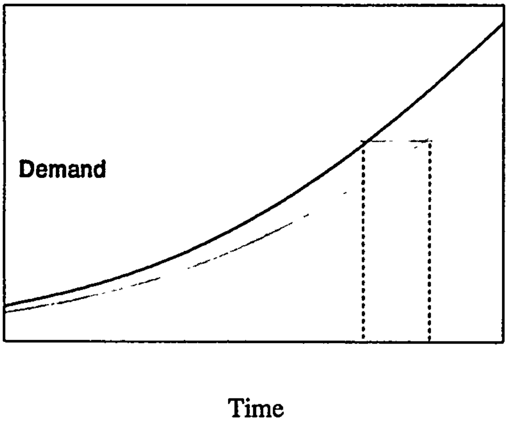


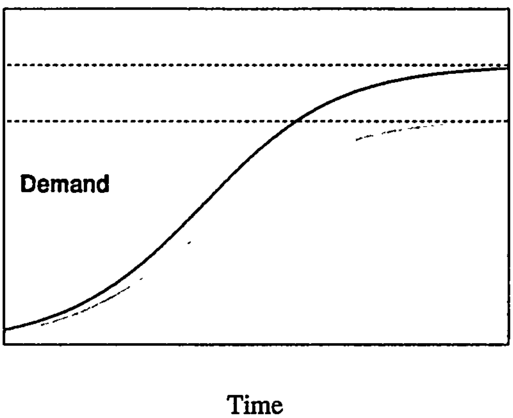
Figure 9
Alternative Growth Models

Exponential Model



The change in efficiency of energy use translates to only delaying for a few years the inevitable growth of demand.

Sustainable Model



The change in efficiency of energy use translates to a permanent lowering of demand and, therefore, pollution for a given level of economic activity.