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April 16, 1992

MEMORANDUM

TO: *Interested Parties*

FROM: *Rob Long*

RE: *Global Climate Change - Science, Economics, Policy and
Technology Cooperation*

Recently, the Washington International Energy Group, an international consulting firm which has been tracking developments on the issue of global climate change for the past several years, compiled the enclosed notebook for several of its clients. The notebook catalogues and abstracts the major studies which have been conducted on issues related to global climate change. In addition to an overview, it contains short summaries on the science, economics, international policy and technology cooperation aspects of the issue. It is clearly the most thorough, yet concise, documentation of relevant material. In addition to the abstracts, each section contains a short summary highlighting the major findings of the most prominent studies.

Recognizing your responsibilities on these issues, I felt this notebook would be helpful to you as a reference document in your work. Should you need additional copies for any of your colleagues working with you on global climate change, please contact me and they will be made available.

Enclosure

GLOBAL CLIMATE CHANGE NOTEBOOK

March 1992

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INTRODUCTION

WASHINGTON INTERNATIONAL ENERGY GROUP

Introduction—Purpose of Notebook

This notebook is the second part of the Washington International Energy Group's report entitled "Global Climate Change: What is Known?"

The first part of the report, the *Overview*, provided background information on the climate change issue, stressing the economic effects of potential climate change policies, the state of climate change science, and United States and other nation's greenhouse gas emissions policies.

This notebook provides back-up information for the *Overview*, focusing on summaries of key research reports. It also includes analyses of four of the key components which affect the climate change debate, they are:

- ▶ the economic effects of potential climate change policies;
- ▶ the state of climate change science;
- ▶ U.S. policy options to combat climate change; and,
- ▶ technology cooperation options to combat climate change.

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What is Known About the Economic Effects of Potential Climate Change Policies

- ▶ Hasty action by the U.S. to adopt measures to reduce emissions of greenhouse gases will hamper economic growth, erode international competitiveness, and lead to a loss of jobs. Even measures such as a moderate carbon tax could result in the loss of more than 700,000 jobs in 1997.
- ▶ Due to size, resource base and climate, the U.S. is more heavily dependent on fossil fuels than many other industrialized countries. Therefore, any policy that curbs fossil fuel use will have a greater impact on the U.S. than on our trading partners.
- ▶ As a precautionary mitigation policy, it would cost less and be far more environmentally effective for the U.S. to assist countries that are less energy efficient to improve their energy efficiency through technology cooperation rather than pursue policies focused on emissions reductions in industrialized nations.

What is Known About Climate Change Science

- ▶ There is no empirical scientific basis for the conclusion that increases in CO₂ and other greenhouse gas emissions will cause changes in world climate.
- ▶ General circulation computer models used to project climate change are too primitive to be the basis for policy decisions because they do not fully integrate significant factors such as cloud cover, ocean interactions, and biofeedbacks. Current temperature records cannot be duplicated by the models.
- ▶ While CO₂ garners most of the public's attention because man-made sources of it can be easily identified, other gases (e.g., methane, nitrous oxide, CFCs, and ozone) are more potent retainers of heat in the atmosphere. Of these gases, only CO₂ has positive ecological value.

Climate Change Policies

- ▶ Through existing programs and new initiatives in the U.S.—implemented for other reasons—U.S. greenhouse gas emissions in the year 2000 are expected to be no higher than they were in 1987.
- ▶ Some of America's trading partners, including several in the European Community, have pledged to stabilize or reduce CO₂ emissions by early in the next century. However, these nations will be unable to turn their pledges into action without unrealistically high levels of energy conservation, drastic industrial structural shifts, and heavy carbon taxes—measures to which none of them have committed due to their negative economic effects.
- ▶ With world population projected to increase 50% by 2015, restrictions on technological innovation in favor of a policy of economic constraint is a dangerous path to the future.

Global Climate Change—What Is Known?

Overview

As the June 1992 United Nations Conference on Environment and Development (UNCED) fast approaches, the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change (INC) is accelerating its efforts to conclude an international agreement on climate change. Many nations believe a convention should include specific commitments to targets and timetables for reducing emissions of greenhouse gases, particularly carbon dioxide (CO₂). The United States has not agreed that such a step is necessary, especially in view of the scientific uncertainties and the serious economic harm that actions to meet restrictive targets would cause. The U.S. has advocated a precautionary action agenda which encourages policies that make economic and environmental sense in and of their own right.

U.S. policy has traditionally sought to achieve the twin goals of economic development and environmental protection because the latter cannot be achieved without the former. This policy must be maintained and strengthened as Congress and the Administration develop an economic recovery program in 1992.

What is already known with confidence about the scientific aspects of the global climate change issue clearly is not sufficient to justify fossil fuel reduction measures beyond those already being implemented under the Clean Air Act Amendments of 1990 and other existing laws. What is known about the economics of global climate change is that the imposition of proposed reduction measures would result in severe economic harm to the U.S. and further job losses when the country is mired in a recession and the timing of recovery remains uncertain.

Pursuing the twin goals of economic development and environmental protection through a focus on a comprehensive program of technology cooperation offers optimal benefits. First, such a program would address environmental and economic development challenges that already exist in developing countries, where the potential for pollution abatement far exceeds that of developed countries. Second, it would create new job opportunities in U.S. industry by deploying technological and managerial expertise in countries where it is most needed. Third, it would help lead to sustainable economic development by accelerating the advancement and utilization of more efficient energy technologies with reduced environmental impacts. All of these measures would bring lasting environmental and economic benefits.

The U.S. has always fostered worldwide progress by pioneering and commercializing technologies which improve the standard of living both for Americans and citizens of other nations. Rejection of technological innovation in favor of a policy of economic constraint is a dubious, if not dangerous, path to the future.

What Is Known About the Economic Effects of Potential Climate Change Policies

Fundamental Economic Considerations

There is no scientific basis to justify costly actions to stabilize or reduce emissions of greenhouse gases (see science section). Efforts to reduce emissions through mechanisms such as carbon taxes or emission caps would cause an immediate decline in economic growth and an increase in unemployment. A recent Organization for Economic Cooperation and Development (OECD) study concludes, "Stabilizing CO₂ emissions [in the United States] may cost as much as all other environmental regulations combined."¹ The overall costs of environmental policies as a percentage of Gross National Product (GNP) are already significantly higher for the U.S. relative to all other OECD countries.²

A 1991 Department of Energy (DOE) report calculates that, even if revenues from a carbon tax are used to reduce the federal deficit, a carbon tax of \$100 per ton would depress overall output for a decade or longer. Losses in GNP are predicted to be as high as 3% in the year 2000.³ In 1990, a DOE report concluded that, while cost estimates of reducing CO₂ emissions are preliminary and subject to dispute, even less is known about the costs of reducing emissions of other greenhouse gases. Despite the uncertainties, there is consensus that costs of stabilizing or reducing CO₂ emissions will be inordinately high.⁴

Some of the policy options now being considered would cut CO₂ emissions through the reduction of fossil fuel use. Because the U.S. is more heavily dependent on fossil fuels than many other industrialized countries, the potential detrimental impacts on the U.S. economy and international competitiveness are great. Even if all the industrialized countries enacted a similar CO₂ policy, U.S. energy costs and electricity rates would rise more than most other countries, putting U.S. industry at a disadvantage relative to foreign competitors.⁵

Perhaps the most devastating cost of CO₂ reduction mandates would be an increase in unemployment. If U.S. industries were forced to pay higher energy prices, the resulting decrease in GNP would be accompanied by significant job losses. Many of the jobs affected by a CO₂ tax would be in basic and essential industries—such as energy, steel, aluminum, mining, and automotive—where unemployment is already high. The employment "multiplier" for these industries is also high. For example, in the coal industry the employment multiplier is calculated to be 6.0; that is, each job in the coal industry supports about six jobs in the entire economy.⁶

A Congressional Budget Office scenario found that even a modest phased-in carbon tax would produce a loss in 1997 of approximately 700,000 jobs.⁷ This is more than the labor force of Wyoming and Montana combined.⁸

Policy Options for Limiting Emissions

Carbon taxes are one of the most controversial policy options being considered. The imposition of a carbon tax—a surcharge on fossil fuels—would have a major impact on energy costs in the U.S. A \$100 per ton carbon tax, for example, would raise the price of gasoline at the pump by about 30 cents per gallon and more than triple the price of coal.⁹

A recent U.S. Department of Commerce study shows that even multilateral restrictions on stationary coal and oil use would result in lower GNP for most industrialized countries,¹⁰ but the OECD estimates show that the U.S. would experience a greater economic decline than any of the OECD countries as a result of such policies.¹¹

Adjustment costs would be tremendous, as electric utilities and other industries would have to spend vast amounts of money replacing plant and equipment. These costs would go beyond the \$25-40 billion per year that will be spent on complying with the Clean Air Act Amendments of 1990.

According to an economic model devised by Dale Jorgenson and Peter Wilcoxon of Harvard University, carbon taxes would raise the price of capital goods, leading to a decrease in investment and long-term declines in GNP.¹² A recent economic study by Charles River Associates estimates that stabilizing CO₂ emissions would require at least a \$200 per ton carbon tax and would cause losses of at least 1.7% of GNP in 2020, increasing to 2.4% in the year 2100.¹³

The 1991 DOE report states, "the scale of fiscal transactions generated by a carbon tax...is so large as to require a general reassessment of fiscal policies."¹⁴

Command-and-control mechanisms and emissions trading are alternatives to carbon taxes to achieve emissions reductions. Because there are no commercial or near-commercial technological fixes to sequester, dispose of, or convert CO₂, a command-and-control system or emissions trading are the only alternatives, other than taxes, currently available to comply with an emissions cap. But, few serious command-and-control proposals have been discussed, and it is generally conceded that this approach has not proven to be the most economically effective. There has been some discussion of an international emissions trading scheme, but there are no active proposals or cost-estimates.

A carbon emissions cap, based on a tradable permit system, would have the identical costs to GNP as a carbon tax.¹⁵ With a carbon tax, the tax is levied in such a way that a certain level of emissions is achieved. With a carbon cap, using tradable permits, the level of emissions would also be set and the price of permits would, over time, tend to be equal to the tax that would achieve that level of emissions. In short, an emissions cap would produce the same detrimental effect on GNP and employment.¹⁶

Other Potential Options

Other potential options exist to reduce emissions of greenhouse gases. Though these as a whole have not been studied and modeled as extensively as carbon taxes, to be effective fiscal or regulatory constraints must be imposed and all will have a cost to the economy.

Fuel switching could force reliance away from less expensive, domestic energy sources to more imported energy, increasing the nation's vulnerability to price shocks and sudden supply interruptions. Use of natural gas, now considered to be cheap and more environmentally acceptable, would also increase. Existing distribution networks in the short-term, and supplies in the long-term, will constrain natural gas availability, leading to price increases, the need for imports, and possible supply shocks. The only other practical fuel solution would be the increased use of nuclear energy, which faces considerable public acceptance problems.

Conservation and energy efficiency measures, including demand-side management programs, have benefits in their own right and will have some effect on the growth of greenhouse gas emissions. More experience is needed to determine the cost of these programs and the extent to which they can actually lead to a sustained reduction in greenhouse gas emissions. It should be noted, though, that economic growth will require additional energy use.

Forestation and agricultural measures are also alternatives. Forestation measures have significant potential as natural absorbers of carbon and are a low cost option. For example, the U.S. tree planting program, which involves planting over a billion trees per year, would absorb the equivalent of 9 million tons of carbon in the year 2000.¹⁷ A proposed Forest Service tree-planting program, which would reforest 15% of U.S. land, would absorb enough CO₂ to reduce the carbon tax levy estimated to be needed to achieve a 20% CO₂ emissions reduction by the year 2000 by 90%.¹⁸ However, such programs could be constrained by the availability and cost of land.

Adaptation, if necessary, may prove to be an acceptable option in some regions. A recent National Academy of Sciences (NAS) report concludes that "the U.S. should be able to adapt to the changes in climate expected to accompany [a potential] greenhouse warming." The report notes that "as societies become more affluent, they have reduced their sensitivity to natural phenomena in many ways."¹⁹ By representing output sectors of society as percents of U.S. total national income, the NAS Adaptation Panel determined that climate change would have a negligible effect on those sectors which account for more than 85% of total national income, a moderate effect on sectors representing 10% of total national income and a severe effect on sectors representing less than 5% of total national income.²⁰ And, while it is premature to reach judgments about varying regional adaptation to global warming, certain sectors, agricultural production for instance, could yield second crops while other regions could be opened to commercial agriculture for the first time.²¹

Technology Cooperation

A positive approach that would encourage economic growth rather than economic constraint would be an approach that focuses on using cleaner, more efficient technologies in developing countries and transitional economies. Through an expanded technology cooperation program, higher efficiency energy production technologies and management skills could be deployed wherever significant population growth and energy demands are expected.

The key question facing policymakers should be how American industry—which has pioneered the development of advanced environmental protection technologies—can be positioned to invest its technological and managerial expertise in the economic development of countries where the potential for pollution abatement, and the potential for greenhouse gas emissions reduction, far exceeds that in the U.S.

The United States already has among the lowest rates of greenhouse gas emissions per unit GNP in the world.²² Greenhouse gas emissions in developed countries as a whole are very low for the value of goods and services produced. By contrast, developing countries and the former centrally planned economies are not nearly as efficient and emit a far greater volume of greenhouse gases for each unit of their GNP. The U.S. emits the heating equivalent of 0.2 kilograms of carbon for each dollar of GNP, while Brazil and Indonesia emit the heating equivalent of approximately 2 kilograms for each dollar of GNP, 10 times as much as the U.S. Poland and China each emit the heating equivalent of approximately 1 kilogram of CO₂ for each dollar of GNP.²³

Energy demand in the developing world is being spurred by rapid population and inevitable industrial growth. The disparity in emissions per unit of GNP will persist and, in all likelihood, increase—unless more advanced means of producing and using energy are used worldwide.

According to the International Energy Agency, as much as 85 percent of the projected increase in global CO₂ emissions is expected to be from developing countries. Reductions in emissions by the U.S. and other industrialized countries would quickly be more than offset by this growth.

The world demand for energy is expected to increase significantly by 2005. Based on commitments of OECD countries, placing the burden of CO₂ emissions reduction chiefly on the developed world would only reduce carbon emissions by 314 million tons, an amount equal to only 3 percent of the projected increase.²⁴ Yet, if current electricity demand in developing countries were supplied by modern power plants of the type of "off the shelf" technology already being used in developed countries, the projected increase in global CO₂ emissions would be reduced by about 1 billion tons annually.²⁵ Moreover, new advanced technologies, such as those developed through DOE's Clean Coal Technology Program, can reduce emissions from coal-fired power plants by as much as 40 percent per unit of electricity produced.²⁶

It is clear that the marginal cost of reducing greenhouse gas emissions by increasing energy efficiency is far less in developing countries than in the developed world.

A technology cooperation program builds on the elements of traditional technology transfer processes where technology, knowledge, and/or information developed in one area is applied and utilized in another. Technology cooperation encompasses needs assessment, technology development, training, and other institution-building mechanisms.²⁷ Technology cooperation actively involves all participating countries in the process.

The U.S. is pursuing cooperative initiatives that will make significant contributions to the goal of sustainable development. For example, a new program of the U.S.-Asian Environmental Partnership, recently announced between the U.S. and Asian nations, will open and facilitate a "fertile environmental market" for American technology and remedial services, supported by the Export-Import Bank and other U.S. agencies.²⁸ U.S. firms will be assisted in marketing their skills and technologies to this \$300 billion market. Other examples of cooperative initiatives include a DOE project in Poland and the Support for Eastern European Democracies (SEED) Program.

In crafting an effective economic recovery program, Congress and the Administration should further expand programs that encourage the strategic investment of U.S. technology in developing countries and countries in transition. This effort would accomplish three things: create new opportunities for American industry; foster international cooperation on global environmental issues and; help other countries achieve their economic development in a more efficient and environmentally responsible manner.

What Is Known About Climate Change Science

There are no empirical findings upon which to conclude that increases in CO₂ and other greenhouse gas emissions will precipitate changes in world climate. Even if there were scientific confirmation that an increase in CO₂ and other greenhouse gas emissions would lead to an increase in mean global temperatures, such an increase may well be within the limits of historic variations, and hence not require drastic action. Natural events, such as solar activity, volcanic eruptions, and ocean current patterns, may all be more dominant elements in determining climate.

In June 1990, Working Group One of the U.N.-sponsored Intergovernmental Panel on Climate Change (IPCC)²⁹ issued a scientific report, on which some governments base their conclusion that immediate action to reduce CO₂ emissions is warranted. The report was adopted in August, 1990. Since that time, many of the conclusions in the summary of the report have been criticized by scientists who suggest that the General Circulation Models (GCMs) used as evidence for the IPCC's conclusions are too primitive to be the basis for policy decisions. Some scientists have stressed the widely divergent results of such models, and note their failure to portray the response of feedback mechanisms to any initial atmospheric warming. Scientists have warned that "policymakers would be wise to invest in the additional resources needed to improve the reliability of greenhouse forecasts before undertaking corrective programs that could turn out to be unnecessary."³⁰ Many scientists do not believe a catastrophic climate change is on the horizon.³¹

S. Fred Singer of the University of Virginia, recently surveyed a group of scientists, many of whom contributed to the IPCC report. The survey concludes that there is no consensus on the climate change issue.³² And in a *Wall Street Journal* article, Singer noted that the IPCC report ignores a number of valid scientific objections to the theoretical calculations that predict a global warming.³³

Climate Models

General Circulation Models: The NAS stresses that existing computerized GCMs do not provide a reliable picture of future climate change scenarios because they only model the atmosphere and do not fully take feedbacks into account. In an April 1991 report, the NAS concluded that, although computer simulations using GCMs are considered the best available tools for predicting climate change, they lack adequately validated representations of factors such as cloud cover feedback, ocean circulation, and hydrologic interactions.³⁴ As stated in their report, "Neither the available climate record nor the limited capabilities of the climate models permit a reliable forecast of the implications of continued accumulations of greenhouse gases in the atmosphere."³⁵

In addition, the IPCC itself notes, "The validation of a number of atmospheric model variables has been handicapped by limitations in the available observed and model data."³⁶ Patrick Michaels of the University of Virginia adds, "...it is indefensible to use GCMs as a basis for any expensive energy policies. The use of knowingly incorrect parameters...should easily be enough to discredit GCMs as vehicles for policy."³⁷

Climate Change Concerns

Temperature: One of the key conclusions from the IPCC scientific report is that "it is not possible to attribute all, or even a large part of the global-mean warming to the enhanced greenhouse effect on the basis of observational data currently available."³⁸ While it is true that there has been a marginal increase in *land-based* temperatures since the mid-1970's, there have been more extreme rises and decreases in the past. Supporting this point, Roy Spencer of the National Aeronautics and Space Administration's (NASA) Marshall Space Flight Center and John Christy of the University of Alabama, while working to determine the reliability of long-term climate models, concluded that the *atmospheric* temperature record from 1979 through late 1988 showed no significant global trend. Spencer and Christy's conclusions were reached using definitive measurements from NASA weather satellites. As the analysis continued into 1989, similar results were reported.³⁹

Patrick Michaels, speaking of the "urban heat island effect," notes that "taking the Earth's temperature from ground-based thermometers is a daunting proposition, owing to the fact that cities tend to grow up around (and artificially warm) their weather stations, and because the site selections for those very stations is climatically non-random. These factors induce systematic errors or biases into the temperature records."⁴⁰

Richard Lindzen, Sloan Professor of Meteorology at the Massachusetts Institute of Technology, concludes that, "Despite popular opinion to the contrary, the quantitative expectation of substantial global warming (more than 1° C or so) arising in the next century because of man's production of minor greenhouse gases (CO₂, chlorofluorocarbons [CFCs], methane, etc.) is without substantive scientific foundation."⁴¹

Sea Level Rise: While some scientists believe that significant sea level rise would accompany global warming, the IPCC notes that, "there is no firm evidence of an acceleration in global mean sea level rise over this century,"⁴² perhaps indicating that predictions of a global warming trend are incorrect. David Aubrey of the Woods Hole Oceanographic Institution stresses that, until more is known about the driving forces behind climate change, it makes no sense to try to predict such "second order" effects as sea level rise.⁴³ While some claim that rising air temperatures may cause increasing snow and ice melting—leading to sea level rise—data also suggests that a rise in CO₂ concentrations may lead to increased snow precipitation in Antarctica, which would have the opposite effect on sea level, possibly causing it to fall by 0.1 to 0.5 meters in the next 100 years.⁴⁴

Desertification: The potential for mass destruction of the world's forests and an increase in desert area have been highlighted as two of the more severe impacts that could accompany changes in climate. Recent evidence suggests, however, that increasing atmospheric CO₂ levels may actually lead to accelerated forest growth and decreasing desertification. Sherwood Idso of the U.S. Agricultural Research Service maintains that, as the air's CO₂ content continues to rise, "Natural ecosystems will [benefit], as Earth's more robust vegetation grows more vigorously and wins back great tracts of land previously lost to desertification. Grasslands will flourish where deserts now lie barren...and forests will make a dramatic comeback to reclaim many areas presently sustaining only brush and scattered shrubs."⁴⁵

Other Possible Causes of Climate Change

Solar Variations: Small variations in solar radiation may cause climate changes as large as those that some believe would be caused by large increases in greenhouse gases. Precise observations of the sun's activity have been taken only for the past decade, and future solar variations could be extremely large.⁴⁶ In November 1991, two Danish geophysicists announced a close statistical correlation between variations in the length of the sunspot cycle and fluctuations in the world's surface temperature over the last 130 years. Analyzing lengths of sunspot cycles, which averaged 11 years, they found that variations in cycle length matched almost perfectly the fluctuations in northern-hemisphere temperatures from the mid-1850s to the mid-1980s. This suggests that temperature records could correlate more closely with solar variation than with changes in the concentration of greenhouse gases.⁴⁷

Additional Factors: Major natural events such as volcanic eruptions, as well as long-term changes in land-use trends can also have significant impacts on climate. Changing ocean current patterns, for example El Niño and La Niña, are capable of setting off chains of events that can affect the weather in many parts of the world. In 1982-83, higher-than-average sea-surface temperatures pumped massive amounts of energy into the atmosphere, bringing on a climatic chain reaction responsible for disastrous drought conditions in some parts of the world and flooding rains in others.⁴⁸

Other Considerations

Greenhouse Gases: While CO₂ garners most of the public attention because man-made sources of it can be more easily identified,⁴⁹ other gases have more potent greenhouse radiative "forcings" that hold more of the Earth's heat.⁵⁰ Although methane (CH₄) has a lower atmospheric concentration than CO₂, its climate forcing effect is much greater than that of CO₂.⁵¹ The global warming potentials (GWP)⁵² of various greenhouse gases, relative to CO₂, over a 20 year time period, are as follows (CO₂'s GWP is listed as 1): methane 63, nitrous oxide 270, and CFC-11 4500. In addition, the production of tropospheric ozone as a result of emissions of methane leads to a large indirect forcing effect. The GWP of the tropospheric ozone created as a result of methane release is 24.⁵³ Therefore, it is necessary to have a comprehensive understanding of the interactions among these greenhouse gases and their relative impacts prior to designing actions to reduce emissions.⁵⁴

Deforestation and Wood Use: Forests are one of the largest carbon "sinks",⁵⁵ containing about 60% of the organic carbon stored on world land surfaces. Destruction of the world's forests, particularly in South America, reduces natural CO₂ absorption. Slash-and-burn agriculture, common in developing countries, releases even more CO₂ into the atmosphere. Furthermore, in those countries where wood is still a primary fuel for cooking and heating, inefficient combustion is a significant factor. Deforestation alone contributes a net equivalent of 50% of the annual total input of CO₂ to the atmosphere from fossil fuel combustion.⁵⁶

Population Growth: Although developing countries currently account for only one-fourth of world greenhouse gas emissions, as they industrialize and their energy demand increases in relation to

their rapidly growing populations, they are projected to surpass the more developed countries in emissions of CO₂ and other greenhouse gases. According to Karl Gawell of Zero Population Growth, between now and 2030, the population added in developing countries will contribute twice the CO₂ emissions as the population added in the industrialized world.⁵⁷

Positive Effects of Increasing CO₂: While proponents of the "popular vision" that a catastrophic climate change is at hand insist that increased CO₂ concentrations in the atmosphere carry only negative effects, evidence to the contrary continues to emerge. Sherwood Idso of the Agricultural Research Service and other researchers have shown that, under certain limits, plants function much better when exposed to increased levels of CO₂. Even in situations where water or nutrients are limited, agricultural research has demonstrated that the relative growth enhancement for plants due to CO₂ enrichment is great. Plants respond even better to CO₂ enrichment at higher temperatures. The NAS notes, "An increasing atmospheric concentration of CO₂ would increase agricultural production by enhancing the use of sunlight and slowing transpiration in some plants."⁵⁸

What the U.S. Is Doing

As a result of existing programs and new initiatives which have been designed for other reasons, the U.S. has taken definitive steps which will reduce greenhouse gas emissions. Emissions of greenhouse gases in the year 2000 are expected to be no higher than they were in 1987. In addition, if there are better incentives for U.S. industry to invest in new capital stock, the rate of growth in CO₂ and other emissions will be substantially curtailed because of the inherently higher efficiency of new technologies. Economic recovery will permit industry to make some of these investments, but that effort will be impaired if industry is forced to shift limited capital to pay higher taxes and/or comply with new command-and-control regulations.

There are several implemented or proposed national policies which are expected to lead to the stabilization of greenhouse gas emissions. DOE estimates that, "the National Energy Strategy (NES) actions are projected to hold...energy-related emissions of greenhouse gases at or below 1990 levels throughout the period to 2030."⁵⁹ The Clean Air Act Amendments of 1990 are strong incentives to increase the efficiency of existing and new power plants and to aggressively pursue energy conservation measures. The "Urban Smog" section of the Amendments mandates requirements to reduce pollution and greenhouse gas emissions in the transportation sector, including tailpipe emissions requirements and clean fleet and alternative fuel vehicle requirements.

The DOE Clean Coal Technology Program will lead to the commercialization of technologies for more efficient and cleaner burning of coal. Under the terms of the Montreal Protocol, CFCs will be phased out by the year 2000. DOE's Conservation and Renewable Program plan, if realized by 2000, will alone reduce CO₂ emissions by 14%. Licensing reform and other legislative and regulatory efforts to strengthen the nuclear option would result in lower greenhouse gas emissions. And, of course, broader incentives to encourage new investment would upgrade plant technology.

U.S. government spending on climate change research accounts for more than 90% of the world-wide government-funded research. FY 1992 spending is \$1.111 billion, more than a 50% increase over FY 1990.

What Other Countries Are Doing

Some of America's trading partners have pledged to stabilize or reduce CO₂ emissions by early in the next century. In reality, these nations have done little to turn their pledges into action. The European Community is evaluating a carbon tax (which would excuse many industries from participating) and a few European countries—for example, Norway, Sweden, and the Netherlands—have levied token carbon taxes, but the total CO₂ reductions stemming from these taxes will be minimal.

Japan has pledged to stabilize CO₂ emissions by the year 2000 (with adjustments for population growth). The Institute of Energy Economics in Japan, however, recently concluded that it is impossible to achieve this goal or sustain it in the future without "an unrealistically high energy conservation rate, drastic industrial structural shifts, and heavy carbon taxes."⁶⁰

The developing countries have made it clear that, in their view, the burden for addressing climate change mitigation should be placed on industrialized countries. As India's delegate to the INC stated, "developing countries are the victims of climate change, not the cause."⁶¹

1. Organization for Economic Cooperation and Development (OECD), *OECD Economic Surveys: United States, 1991*, November 1991.
2. Ibid. By the year 2000, the U.S. will be spending 2.8% of its GNP on environmental controls, higher than any other OECD country.
3. U.S. Department of Energy (DOE), Office of Environmental Analysis, Deputy Under Secretary for Policy, Planning and Analysis, *Limiting Net Greenhouse Gas Emissions in the United States: Report to the Congress of the United States*, September 1991.
4. U.S. DOE, Office of Policy, Planning and Analysis, *The Economics of Long Term Global Climate Change: A Preliminary Assessment*, Report of an Interagency Task Force, September 1990.
5. Op. cit., U.S. DOE, *Economics of Long Term Global Climate Change*.
6. Gordon, Richard L. and A. Rose, "The Economic Impact of Coal," *Coal Voice*, Special Report, 1991.
7. Using a model of the estimated effects of a phased-in carbon charge of \$100 per ton, analyzed in a Congressional Budget Office report, a carbon tax phased in beginning in 1991 causes a gradual increase in unemployment. Based on the model, the additional unemployment caused by the phased-in carbon tax is highest in 1997, where it amounts to a 0.52% absolute change from baseline unemployment. According to calculations using a projection of the 1997 labor force, provided by the U.S. Department of Labor, the additional change as a result of the carbon tax amounts to over 700,000 jobs. The scenario is more severe if the carbon tax were to be imposed all at once. Sources for figures are: Congressional Budget Office (CBO), *Carbon Charges as a Response to Global Warming: the Effects of Taxing Fossil Fuels*, August 1990; CBO Natural Resources and Commerce Division; and U.S. Department of Labor, Bureau of Labor Statistics, Office of Employment Projections.
8. Other states with a labor force under 700,000 include: North Dakota, South Dakota, Alaska, Delaware, Hawaii, Idaho, Maine, Nevada, New Hampshire, Rhode Island, Vermont, and the District of Columbia. Source: U.S. Department of Labor, Bureau of Labor Statistics, Office of Employment and Unemployment Statistics, Office of Current Employment Analysis, Local Area Unemployment Statistics Division.
9. Op. cit., OECD. See Also: Gale, Roger W., "A Carbon Tax Could Blacken Economy," *Wall Street Journal*, July 6, 1990; and Gale, Roger W., "The Economic Impact of Global Warming: Competitiveness is at Stake," Speech before the 17th Annual Electric Utility Conference, October 10, 1991.
10. DRI/McGraw-Hill, *The Economic Effects of Restrictions on Coal and Petroleum Fuels in Stationary Uses*, Report for the U.S. Department of Commerce, April 1991.
11. Op. cit., OECD.

14. Op. cit., U.S. DOE, *Limiting Net Greenhouse Gas Emissions*.
15. Op. cit., U.S. DOE, *Limiting Net Greenhouse Gas Emissions*. A 1991 DOE study states, "Due to the dual nature of prices and quantities, the auction price that emitters would be willing to pay for the right to emit these gases is equivalent to the tax level that would induce similar reductions in these gases. Therefore, the cost and impact of a cap program would be identical to the carbon tax case."
16. See Also: Gale, Roger W., "Environmental Initiatives: Based on the U.S. Clean Air Act Amendments," Speech before the World Energy Conference, Asia-Pacific Region, June 1991; and Gray, C. Boyden, Counsel to the President, Memorandum to Richard B. Stewart, Assistant Attorney General, December 14, 1989.
17. Cristofaro, Alex and Joel Scheraga, *Policy Implications of a Comprehensive Greenhouse Gas Budget: Draft Report*, Report for the U.S. Environmental Protection Agency, September 1990.
18. Holden, Constance, Editor, "Briefings: Greenhouse Gas Tax," *Science*, January 10, 1992.
19. National Academy of Sciences (NAS), *Policy Implications of Greenhouse Warming-Report of the Synthesis Panel*, April 1991.
20. National Academy of Sciences (NAS), *Policy Implications of Greenhouse Warming-Report of the Adaptation Panel*, August 1991.
21. Op. cit., NAS Synthesis Panel.
22. World Resources Institute, *World Resources 1990-91*, New York: Oxford University Press, 1990.
23. Ibid.
24. Zimmermeyer, Gunder, *Potentials for CO₂ Reduction as an Example for Prudent Policies to Protect the Climate*, Presented to the International Committee on Coal Research in Washington, D.C., October 1991.
25. Ibid.
26. U.S. DOE Statistics, 1991.
27. Reinstein, Robert, Deputy Assistant Secretary of State for the Environment, Health and Natural Resources, and Chief U.S. INC Negotiator, Statement at the Third INC Framework Convention Session, Nairobi, Kenya, September 1991.
28. "U.S.-Asian Partnership Creating 'Fertile' Environmental Markets," *World Environment Report*, January 7, 1992.
29. Intergovernmental Panel on Climate Change (IPCC), Working Group One, *Scientific Assessment of Climate Change*, June 1990.
30. George C. Marshall Institute, *Scientific Perspectives on the Greenhouse Problem*, 1989.

31. Michaels, Patrick, "Greenhouse Disaster," Summary of remarks submitted to *Science*, September 28, 1990.
32. Singer, S. Fred and Jay S. Winston, *Singer-Winston Survey of IPCC Reviewers*, October 1991.
33. S. Fred Singer, "No Scientific Consensus on Greenhouse Warming," *Wall Street Journal*, September 23, 1991.
34. Op. cit., NAS, *Policy Implications*.
35. Ibid.
36. Op. Cit., IPCC, *Scientific Assessment*. Also, from U.S. Environmental Protection Agency, *Policy Options for Stabilizing Global Climate*, December 1990, "...the simplified atmospheric chemistry and ocean models employed [in the study of climate change] may not adequately reflect the underlying processes..."
37. Michaels, Patrick, Statement before the California Energy Commission, 1991.
38. Op. cit., IPCC, *Scientific Assessment*.
39. Spencer, Roy, "Precise Measurements of Global Temperature Trends from Satellites," *Science*, March 30, 1990.
40. Op. cit., Michaels, Testimony before the California Energy Commission.
41. Lindzen, Richard S., Massachusetts Institute of Technology, Statement to the House Committee on Science, Space and Technology, October 8, 1991.
42. Op. cit., IPCC, *Scientific Assessment*.
43. Conversation with David Aubrey, January 15, 1992.
44. Meier, Mark F., *Role of Land Ice in Present and Future Sea Level Change*, University of Colorado, 1990. Also from Stevens, William K., "Scientists Suggest Global Warming Could Hasten the Next Ice Age," *New York Times*, January 21, 1992, a January 1992 study by Canadian and American scientists strengthens this argument. Gifford Miller of the University of Colorado and Anne de Vernal of the University of Quebec at Montreal concluded that if global warming proceeds as some have forecast, the Northern Hemisphere's ice sheets could expand as much as they did at the start of the last Ice Age (when the world's climate was warmer than it is today). After reconstructing conditions at the start of the last glaciation 122,000 years ago, Miller and de Vernal concluded that a global warming would cause more sea-water to evaporate, producing moisture for increased precipitation in the winter. Such precipitation would fall as snow, in turn compressing into ice.
45. Idso, Sherwood, Testimony before the California Energy Commission, November 19, 1991.
46. U.S. Environmental Protection Agency, *The Potential Effects of Global Climate Change on the United States*, December 1989.

47. *Science*, November 1991. Analysis by Dr. Eigil Friis-Christensen and Dr. Knud Lassen of the Danish Meteorological Institute in Copenhagen.
48. Stevens, William K., "Earth's Temperature Has Dropped a Little After a Warm Spell," *New York Times*, December 24, 1991.
49. Recently, the Worldwatch Institute reported that CO₂ emissions have actually decreased over the last two years, with indications that they may decrease further in 1992. Although CO₂ levels are generally expected to increase over time, the increase may not be consistent. Press Release, Worldwatch Institute, December 1991.
50. Op. cit., IPCC, *Scientific Assessment*. The climate of the Earth is affected by changes in radiative forcing due to several sources (known as radiative forcing agents). Such sources include the concentration of radiatively active (greenhouse) gases, solar radiation, aerosols, and albedo. "For the period 1765 to 1990, CO₂ has contributed about 61% of the forcing, methane 17% plus 6% from stratospheric water vapor, N₂O 4% and the CFCs 12%. For the decade 1980 to 1990, about 56% of the forcing has been due to changes in CO₂, 11% due to the direct effects of [methane] CH₄ and 4% via stratospheric water vapor, 6% from N₂O and 24% from the CFCs."
51. Craig, H. and C.C. Chou, *Geophysics Research Letter* 9, 1982.
52. Op. cit., IPCC, *Scientific Assessment*. "GWP" is an index which allows the climate effects of the emissions of greenhouse gases to be compared. The GWP depends on the position and strength of the absorption bands of the gas, its lifetime in the atmosphere, its molecular weight and the time period over which the climate effects are of concern.
53. Op. cit., IPCC, *Scientific Assessment*.
54. Op. cit., Gray.
55. A "sink" is a natural absorption mechanism which removes a gas from the atmosphere.
56. Sullivan, K.M., *The Effect of CO₂ Emissions from Coal Fired Power Plants*, The World Coal Institute, July 1989.
57. Carr, R., *Population as a Cause of Global Warming*.
58. Op. cit., NAS, *Policy Implications*.
59. Op. cit., DOE, *Limiting Net Greenhouse Gas Emissions*.
60. Tomitate, Takeo, Managing Director, Institute of Energy Economics, Tokyo, Statement before a meeting of the Atlantic Council, November 1991.
61. Menon, Pranhakar, Statement as the Indian representative at the first INC session in Chantilly, Virginia, February 5, 1991.

ECONOMICS

WASHINGTON INTERNATIONAL ENERGY GROUP

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1. Manne, Alan S., and Richard G. Richels, *Global CO₂ Emission Reductions—the Impacts of Rising Energy Costs*, Stanford University and Electric Power Research Institute, February 1990.
2. *Carbon Charges as a Response to Global Warming: the Effects of Taxing Fossil Fuels*, Congressional Budget Office, August 1990.
3. *The Economics of Long-Term Global Climate Change: A Preliminary Assessment*, U.S. Government Interagency Task Force, Office of Policy, Planning and Analysis, U.S. Department of Energy, Draft, September 1990.
4. Jorgenson, Dale W. and Peter J. Wilcoxon, *The Cost of Controlling U.S. Carbon Dioxide Emissions*, Harvard University, September 1990.
5. *The Economic Effects of Restrictions on Coal and Petroleum Fuels in Stationary Uses*, Report for the U.S. Department of Commerce, DRI/McGraw Hill, April 1991.

6. *Limiting Net Greenhouse Gas Emissions in the United States: Report to the Congress of the United States*, U.S. Department of Energy, Office of Environmental Analysis, Deputy Under Secretary for Policy, Planning and Analysis, September 1991.
7. *Assessment of Greenhouse Gas Emissions Policies on the Electric Utility Industry: Costs, Impacts, and Opportunities, Draft Final Report*, ICF Resources, prepared for Edison Electric Institute, November 1991.
8. Montgomery, W. David, *The Cost of Controlling Carbon Dioxide Emissions*, Charles River Associates, December 1991.

What is Known About the Economic Effects of Potential Climate Change Policies

Overview

The feasibility of any climate change policy hinges on its economic ramifications.

When analyzing the potential economic effects of climate change policies, three points emerge from the debate. They are as follows:

- 1) Just as scientists disagree over the science of global climate change, economists disagree about the nature of potential economic effects.
- 2) The models used to predict climate change economics vary greatly. No model is perfect. By their very nature, models incorporate simplified assumptions in order to clarify interactions. All economic climate change models being used today can be criticized on some level.
- 3) When considering CO₂ emissions caps, whether they be implemented with carbon taxes, emissions trading programs, or command-and-control measures, most models predict some degree of economic contraction—specifically, a decline in GNP and employment.

Fundamental Economic Considerations

There is no scientific basis to justify costly actions to stabilize or reduce emissions of greenhouse gases (see science section). Efforts to reduce emissions through mechanisms such as carbon taxes or emission caps would cause a decline in economic growth and an increase in unemployment.

A recent Organization for Economic Cooperation and Development (OECD) study concludes, "Stabilizing CO₂ emissions [in the United States] may cost as much as all other environmental regulations combined."¹ The overall costs of environmental policies as a percentage of Gross National Product (GNP) are already significantly higher for the U.S. relative to all other OECD countries.²

A 1990 U.S. Department of Energy (DOE) report, *The Economics of Long-Term Global Climate Change*, states that:

"The benefits and costs of proposed policy actions should be evaluated under a broad range of outcomes that reflect the significant

uncertainties that pervade the global climate issue. Flexible policies that can easily be reversed or expanded, and policies that can be justified for reasons other than climate change should be highly valued."³

Some policy options now being debated would cut CO₂ emissions through the reduction of fossil fuel use. Because the U.S. is more heavily dependent on fossil fuels than many other industrialized countries, the potential detrimental impacts on the U.S. economy and international competitiveness are great.

Fuel Price Changes per \$100 Carbon Tax			
Fuel	Base Cost(\$)	Added Cost(\$)	Added Cost(%)
Crude Oil (\$/bbl)	16.01	12.19	73
Gasoline (\$/gal)	0.98	0.26	27
Heating Oil, distillate (\$/gal)	0.89	0.29	33
Wellhead Natural Gas (\$/tcf)	1.81	1.49	82
Residential Natural Gas (\$/tcf)	5.87	1.50	25
Minemouth Coal (\$/short T)	23.02	55.33	240
Utility Coal (\$/short T)	33.51	55.33	165
Electricity (¢/kwh)	6.5¢	1.76¢	27

Notes: 1989 constant dollars. Base year 1990.

Source: U.S. Department of Energy, *Limiting Net Greenhouse Gas Emissions in the United States*

Even if all the industrialized countries enacted a similar CO₂ policy, U.S. energy costs and electricity rates would rise more than those of other countries, putting U.S. industry at a disadvantage relative to foreign competitors.⁴

A recent DOE report calculates that, even if revenues from a carbon tax are used to reduce the federal deficit, a carbon tax of \$100 per ton would depress overall output for a decade or longer. Losses in GNP are predicted to be as high as 3% in the year 2000.⁵

Perhaps the most devastating cost of CO₂ reduction mandates would be an increase in unemployment. If U.S. industries were forced to pay higher energy prices, the resulting decrease in GNP would be accompanied by significant job losses. Many of the jobs affected by a CO₂ tax would be in basic and essential industries—such as energy, steel, aluminum, mining, and automotive—where unemployment is already high. The employment "multiplier" for these industries is also high. For example, in the coal industry the employment multiplier is calculated to be 6.0; that is, each job in the coal industry supports about six jobs across the entire economy.⁶

A Congressional Budget Office scenario found that a phased-in carbon tax would produce a loss in 1997 of approximately 700,000 jobs.⁷ This is more than the labor force of Wyoming and Montana combined.⁸

Policy Options for Limiting Emissions

Carbon taxes are one of the most controversial policy options being considered. The imposition of a carbon tax—a surcharge on fossil fuels—would have a major impact on energy costs in the U.S.

A \$100 per ton carbon tax, for example, would raise the price of gasoline at the pump by about 30 cents per gallon and more than triple the price of coal.⁹

A recent U.S. Department of Commerce study shows that even multilateral restrictions on stationary coal and oil use would result in lower GNP for most industrialized countries,¹⁰ but the OECD estimates show that the U.S. would suffer the most of all the OECD countries as a result of such policies.¹¹

Adjustment costs would be tremendous, as electric utilities and other industries would have to spend vast amounts of money replacing plant and equipment. These costs would go beyond the \$25-40 billion per year that will be spent on complying with the Clean Air Act Amendments of 1990.

Economists have devised *carbon tax models* in order to determine the levy on CO₂ needed to achieve specific reductions and to understand the potential effect of such taxes on macroeconomic indicators domestically and worldwide.

Such models are described in the articles summarized in the Economic Summaries section following this section of the report:

- 1) *The Cost of Controlling Carbon Dioxide Emissions*, by W. David Montgomery, Charles River Associates, Inc., December 1991.
- 2) *The Cost of Controlling U.S. Carbon Dioxide Emissions*, by Dale W. Jorgenson and Peter J. Wilcoxon, Harvard University, September 1990.
- 3) *Global CO₂ Emission Reductions—The Impacts of Rising Energy Costs*, by Alan S. Manne and Richard G. Richels, Stanford University and the Electric Power Research Institute, February 1990.

The most widely-used econometric models—Global 2100, Jorgenson-Wilcoxon, Edmonds-Reilly, and DRI—all attempt to evaluate the level of CO₂ taxes needed to achieve a certain emissions reduction goal. They all predict a certain amount of economic contraction, although, because of differing assumptions, they vary in the degree and duration of the declines that they predict.

Also, each of the models has its own set of inadequacies.¹² For example, the model devised by Dale Jorgenson and Peter Wilcoxon of Harvard University predicts that a tax of \$60 would be necessary to reduce emissions to desired levels (over \$100 lower than that predicted by Global 2100, Edmonds-Reilly, or DRI), leading to a GNP loss of 1.6%. The Jorgenson-Wilcoxon model has been criticized, however, for being too long-term. Because of the assumption that the capital stock is perfectly mobile, the model exaggerates the effect of an energy tax on emissions; in reality, there are greater costs associated with switching, and a larger tax would be needed to entice an electricity producer to switch fuels. Also, the model assumes no limits on natural gas resources, so it is likely to underestimate how large a tax would be required to achieve stable emissions, especially in later years.¹³ Based on these criticisms, it can be construed that the Jorgenson-Wilcoxon model severely underestimates the amount of tax necessary to achieve the desired emissions. If a larger tax were used, the model would indicate a much more severe impact on GNP.

According to the Jorgenson-Wilcoxon, carbon taxes would raise the price of capital goods, leading to a decrease in investment and long-term declines in GNP.¹⁴ A recent economic study by Charles River Associates estimates that stabilizing CO₂ emissions would require at least a \$200 per ton carbon tax and would cause losses of at least 1.7% of GNP in 2020, increasing to 2.4% in the year 2100.¹⁵

The 1991 DOE report addresses yet another aspect of the carbon tax issues, concluding that "the scale of fiscal transactions generated by a carbon tax...is so large as to require a general reassessment of fiscal policies."¹⁶

Command-and-control mechanisms and emissions trading are alternatives to carbon taxes for achieving targets and timetables. Because there are no commercial or near-commercial technological fixes to sequester, dispose of, or convert CO₂, a command-and-control system or emissions trading are the only alternatives, other than taxes, currently available to comply with an emissions cap. But few serious command-and-control proposals have been discussed, and it is generally conceded that this approach has not proven to be the most economically effective. There has been some discussion of an international emissions trading scheme, but there are no active proposals or cost-estimates.

If a carbon emissions cap were adopted to meet targets and timetables based on tradable permits, a carbon cap would have the identical costs to GNP as a carbon tax.¹⁷ With a carbon tax, the tax is levied in such a way that a certain level of emissions is achieved. With a carbon cap, using tradable permits, the level of emissions would also be set and the price of permits would, over time, tend to be equal to the tax that would achieve that level of emissions. In short, an emissions cap would produce the same detrimental effect on GNP and employment.¹⁸

Other Potential Options

Other potential options exist to reduce emissions of greenhouse gases. Though these as a whole have not been studied and modeled as extensively as carbon taxes, all will have a cost to the economy.

Fuel switching could force reliance away from less expensive, domestic energy sources to more imported energy, increasing the nation's vulnerability to price shocks and sudden supply interruptions. Use of natural gas, now considered to be cheap and more environmentally acceptable, would also increase. Existing distribution networks in the short-term, and supplies in the long-term, will constrain natural gas availability, leading to price increases, the need for imports, and possible supply shocks. The only other practical fuel solution would be the increased use of nuclear energy, which faces considerable public acceptance problems.

Conservation and energy efficiency measures, including demand-side management programs, have benefits in their own right and will have some effect on the growth of greenhouse gas emissions. More experience is needed to determine the cost of these programs and the extent to which they can actually lead to a sustained reduction in greenhouse gas emissions. It should be noted, though, that economic growth will almost certainly require additional net energy use.

Forestation and agricultural measures are also alternatives. Forestation measures have tremendous potential because they are a lower-cost option, and trees are natural absorbers of carbon. For example, the U.S. tree planting program, which involves planting over a billion trees per year, would absorb the equivalent of 9 million tons of carbon in the year 2000.¹⁹ A proposed Forest Service tree-planting program to reforest 15% of U.S. land would absorb enough CO₂ to reduce by 90% a carbon tax levy estimated to be needed to achieve a 20% CO₂ emissions reduction by the year 2000.²⁰ However, such programs require a long growing cycle and could be constrained by the availability and cost of land.

Adaptation, if necessary, may prove to be an acceptable option in some regions. A recent National Academy of Sciences (NAS) report concludes that "the U.S. should be able to adapt to the changes in climate expected to accompany greenhouse warming." The report notes that "as societies become more affluent, they have reduced their sensitivity to natural phenomena in many ways." While it is premature to reach judgments about the overall impact of global warming on agricultural production, some regions of the world could produce second crops and others could be opened to commercial agriculture for the first time.²¹

International Aspects

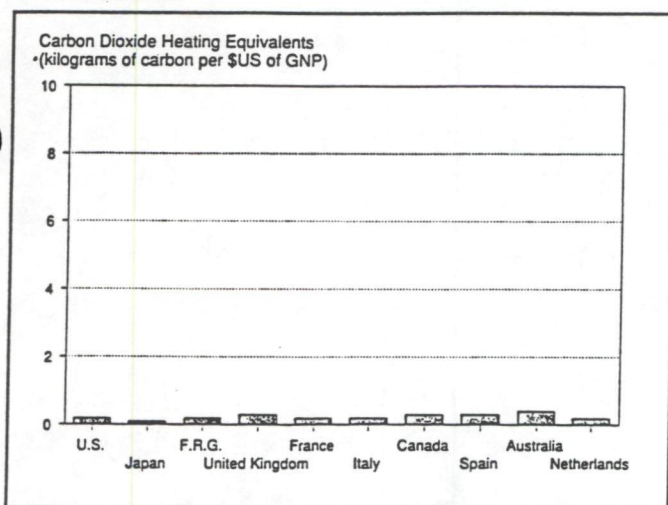
When considering the economics of climate change policy, international aspects should also be discussed. Two parts, specific to the international aspect, are worth noting:

U.S. competitiveness depends on whether the U.S. acts unilaterally or multilaterally. A carbon tax (or other measure to curb CO₂ emissions) enacted unilaterally, or under circumstances where U.S. trading partners do not tax their export sectors, would be devastating. As a result of higher energy costs and the resulting price inflation, U.S. goods would instantly become relatively more expensive on world markets, competitiveness would be eroded, and the trade balance would worsen.

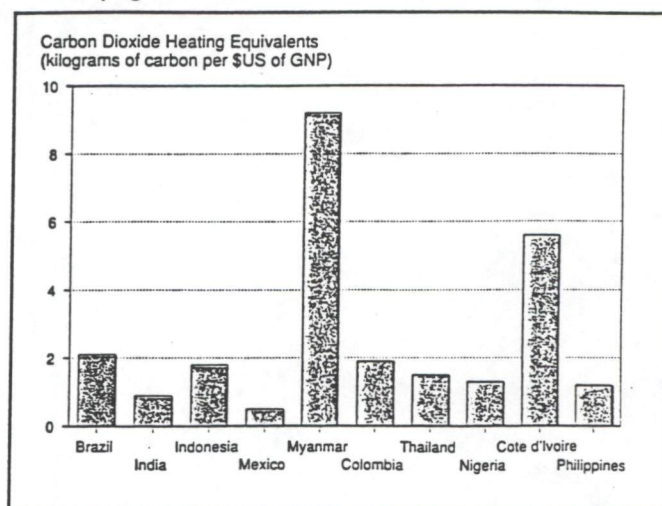
The role of developing countries is crucial. Developing countries will soon come to be the largest CO₂ emitters, and currently they have the highest levels of CO₂ emissions per unit of GNP.

Net Greenhouse Gas Emissions per U.S. Dollar of Gross National Product, 1987

OECD Countries



Developing Countries



Source: World Resources Institute calculation based on Chapter 24, "Atmosphere and Climate," Table 24.2.

For these reasons, it is important to target developing countries to achieve emissions reductions. According to the 1991 Department of Energy report:

"The United States acting alone cannot hold global greenhouse gas or carbon emissions constant. Even the most extraordinary efforts of the entire OECD acting alone could not hold global fossil fuel carbon emissions constant beyond the year 2020. By the year 2020, non-

OECD fossil fuel carbon emissions are expected to exceed present global emissions."²²

The best means to assist developing countries in economic growth as well as environmental protection is through a program of technology cooperation, which will have an incidental benefit to U.S. industry and competitiveness as well.

Conclusion

The science of climate change is highly uncertain. As long as it remains that way, it is impossible to conduct an accurate cost-benefit analysis, because the benefits cannot be clearly known. Likewise, the costs are not known with certainty; however, at least in the case of costs, the direction of change is virtually indisputable: a policy to severely curtail CO₂ emissions would exert downward pressure on the economy, leading to a decline in GNP, job losses, and a decline in investment.

A 1990 Congressional Budget Office report states that:

"The ultimate question [is] whether the costs imposed by carbon charges, or any other program equally effective in controlling carbon dioxide emissions, would be worth bearing in order to delay the increase in carbon dioxide concentration....Uncertainties surrounding both the benefits and the costs of such policies make answering this question difficult."²³

Because an accurate cost-benefit assessment cannot be undertaken, economic effects of CO₂ limitation policies cannot be known, and the risk exists that tremendous costs could be undertaken for virtually no benefit. For this reason, it behooves policymakers to pursue prudent policies, such as technology cooperation, that are not detrimental to the economy.

According to W. David Montgomery of Charles River Associates:

"...the quantifiable economic benefits of immediate reductions in carbon dioxide emissions appear to be quite small (Nordhaus, NAS). Accepting this conclusion turns attention to whether there might also be effective measures to reduce emissions that would entail little or no cost. Action by the U.S. government to cause these measures to be adopted might represent insurance against the possible dangers of climate change, and would form a "no-regrets" policy."²⁴

1. Organization for Economic Cooperation and Development (OECD), *OECD Economic Surveys: United States*, 1991, November 1991.
2. Ibid. By the year 2000, the U.S. will be spending 2.8% of its GNP on environmental controls, higher than any other OECD country.
3. U.S. Department of Energy (DOE), Office of Policy, Planning and Analysis, *The Economics of Long-Term Global Climate Change: A Preliminary Assessment*, Report of an Interagency Task Force, September 1990.
4. Op. cit., *The Economics of Long Term Global Climate Change*.
5. DOE, Office of Environmental Analysis, Deputy Under Secretary for Policy, Planning and Analysis, *Limiting Net Greenhouse Gas Emissions in the United States: Report to the Congress of the United States*, September 1991. Also, a 1990 DOE study found that, while cost estimates of reducing CO₂ emissions are preliminary and subject to dispute, even less is known about the costs of reducing emissions of other greenhouse gases. Despite the uncertainties, there is consensus that costs of stabilizing or reducing CO₂ emissions will be inordinately high. From Op. cit., DOE, *The Economics of Long Term Global Climate Change*.
6. Gordon, Richard L. and A. Rose, "The Economic Impact of Coal," *Coal Voice*, Special Report, 1991.
7. Using a model of the estimated effects of a phased-in carbon charge of \$100 per ton, analyzed in a Congressional Budget Office report, a carbon tax phased in beginning in 1991 causes a gradual increase in unemployment. Based on the model, the additional unemployment caused by the phased-in carbon tax is highest in 1997, where it amounts to a 0.52% absolute change from baseline unemployment. According to calculations using a projection of the 1997 labor force, provided by the U.S. Department of Labor, the additional change as a result of the carbon tax amounts to over 700,000 jobs. The scenario is more severe if the carbon tax were to be imposed all at once. Sources for figures are: Congressional Budget Office (CBO), *Carbon Charges as a Response to Global Warming: the Effects of Taxing Fossil Fuels*, August 1990; CBO Natural Resources and Commerce Division; and U.S. Department of Labor, Bureau of Labor Statistics, Office of Employment Projections.
8. Other states with a labor force under 700,000 include: North Dakota, South Dakota, Alaska, Delaware, Hawaii, Idaho, Maine, Nevada, New Hampshire, Rhode Island, Vermont, and the District of Columbia. Source: U.S. Department of Labor, Bureau of Labor Statistics, Office of Employment and Unemployment Statistics, Office of Current Employment Analysis, Local Area Unemployment Statistics Division.
9. Op. cit., OECD. See Also: Gale, Roger W., "A Carbon Tax Could Blacken Economy," *Wall Street Journal*, July 6, 1990; and Gale, Roger W., "The Economic Impact of Global Warming: Competitiveness is at Stake," Speech before the 17th Annual Electric Utility Conference, October 10, 1991.
10. DRI/McGraw-Hill, *The Economic Effects of Restrictions on Coal and Petroleum Fuels in Stationary Uses*, Report for the U.S. Department of Commerce, April 1991.
11. Op. cit., OECD.
12. For an analysis of the models' strengths and weaknesses, see Montgomery, W. David, *The Cost of Controlling Carbon Dioxide Emissions*, Charles River Associates, Inc., December 1991.
13. Op. cit., Montgomery

14. Jorgenson, Dale W. and Peter J. Wilcoxon, *The Cost of Controlling U.S. Carbon Dioxide Emissions*, Harvard University, September 1990.
15. Montgomery, W. David, *The Cost of Controlling Carbon Dioxide Emissions: Final Report*, Charles River Associates Inc., Washington, D.C., December 1991.
16. Op. cit., U.S. DOE, *Limiting Net Greenhouse Gas Emissions*.
17. A 1991 DOE study states, "Due to the dual nature of prices and quantities, the auction price that emitters would be willing to pay for the right to emit these gases is equivalent to the tax level that would induce similar reductions in these gases. Therefore, the cost and impact of a cap program would be identical to the carbon tax case." Op. cit., U.S. DOE, *Limiting Net Greenhouse Gas Emissions*.
18. See Also: Gale, Roger W., "Environmental Initiatives: Based on the U.S. Clean Air Act Amendments," Speech before the World Energy Conference, June 1991; and Gray, C. Boyden, Counsel to the President, Memorandum to Richard B. Stewart, Assistant Attorney General, December 14, 1989.
19. Cristofaro, Alex and Joel Scheraga, *Policy Implications of a Comprehensive Greenhouse Gas Budget: Draft Report*, Report for the U.S. Environmental Protection Agency, September 1990.
20. Holden, Constance, Editor, "Briefings: Greenhouse Gas Tax," *Science*, January 10, 1992.
21. National Academy of Sciences (NAS), *Policy Implications of Greenhouse Warming*, April 1991.
22. Op. cit., U.S. DOE, *Limiting Net Greenhouse Gas Emissions*.
23. Congressional Budget Office (CBO), *Carbon Charges as a Response to Global Warming: The Effects of Taxing Fossil Fuels*, August 1990.
24. Op. cit., Montgomery.

Global CO₂ Emission Reductions—the Impacts of Rising Energy Costs

Alan S. Manne and Richard G. Richels, Stanford University and the Electric Power Research Institute, February 1990.

Key Points

- ▶ ***Even if very modest emission reduction goals are set, the U.S. could suffer a GNP loss of as much as 3%, while European nations suffer losses of 1-2%.***
- ▶ ***Without a global agreement, CO₂ emissions would increase dramatically.***

In this paper, Manne and Richels explain their *Global 2100* model and explore the impacts of a carbon emissions limit on each of the five regions covered in their model.

The analysis is based on ETA-MACRO, "a model of two-way linkage between the energy sector and the balance of the economy." It is a "merger between ETA (a process model for energy technology assessment) together with a macroeconomic growth model providing for substitution between capital, labor and energy inputs."

Manne and Richels compare their scenarios to a base case of unconstrained carbon emissions.

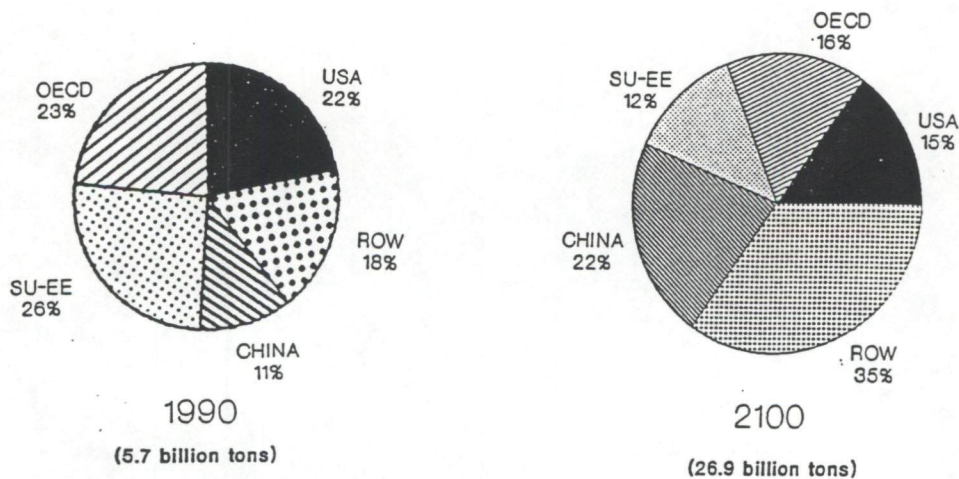
Regarding the international aspects of carbon emissions limits, Manne and Richels state that "there are many possible ways to define a global agreement on carbon emissions. Although there is considerable disagreement over the appropriate level of reduction, there is agreement that the burden must fall disproportionately on the industrialized nations... The developing nations are unlikely to accept any agreement which fails to provide for some increase in their carbon emissions."

For these studies, Manne and Richels assume that industrialized nations reduce CO₂ emissions by 20% below current levels, and developing nations limit their emissions to twice their 1990 levels. The authors note that these are not very radical reductions, but that they do represent a significant reduction in emissions relative to the base case scenario. The authors explain that achieving *worldwide* emissions reductions of 20% or more is difficult because of the primary need to reduce per capita income inequalities between different countries.

Conclusions

- ▶ "In the absence of an international agreement to limit growth, carbon emissions are likely to increase considerably, perhaps by a factor of four or more over the next century."

Unconstrained Carbon Emissions Scenario



- ▶ The tax necessary to achieve even the low emissions reductions recommended by Manne and Richels would be as high as \$250 per ton of carbon.
- ▶ "For the USA, the effects of a carbon constraint do not begin to have measurable macroeconomic consequences until after 2000. At that point the rise in energy prices begins to have a significant effect upon the share of gross output available for current consumption and investment. By 2030, roughly 3% of the total annual U.S. GDP is lost as a consequence of the carbon constraint. This percentage remains roughly constant for the remainder of the time horizon."
- ▶ "For the other OECD countries, measurable macroeconomic consequences do not begin to accrue until 2010, and the annual losses in total consumption are limited to the 1-2% range. The costs of the carbon constraint are somewhat lower than those in the USA" due to a higher proportion of undiscovered oil, larger nuclear power industries, and lower energy/GNP ratios.

Carbon Charges as a Response to Global Warming: The Effects of Taxing Fossil Fuels

Congressional Budget Office (CBO), August 1990

Key Points

- ▶ ***A carbon charge may be an effective means of reducing CO₂ emissions. However, rapidly imposing a severe charge to achieve a high level of reductions would falter U.S. economic growth and increase unemployment.***
- ▶ ***Although the report notes continuing uncertainties in the existing forecasts and makes no specific recommendations, it does conclude that unilateral action by the U.S. would not be cost-effective when compared to international cooperation.***

Prepared at the request of the Senate Committee on Energy and Natural Resources, this report investigates the economic costs of imposing taxes on fossil fuels as a means to reduce emissions of carbon dioxide (CO₂) emissions. Yet, the report stresses, "In keeping with CBO's mandate to provide nonpartisan analysis, no recommendations are made."

According to the study, a gradually introduced carbon charge reaching \$100 per ton of carbon (in 1988 dollars) by the year 2000 would probably stabilize U.S. CO₂ emissions through the year 2000.

The study calculates that if the U.S. unilaterally imposed a charge of \$100 per ton, it might delay the doubling of global carbon dioxide concentrations by only a few years, while a charge of that amount imposed by all countries might buy almost two decades.

While declaring that carbon charges could be effective in reducing CO₂ emissions from fossil fuel combustion in the U.S., the report warns that achieving much greater reductions by the year 2000 would be unlikely without rapid and massive changes in energy production and use, and possible economic peril as a result. "Imposing carbon charges rapidly enough and at a high enough level to achieve reductions in U.S. emissions would risk several years of economic stagnation and high unemployment".

The report advises, "Rapidly imposing large charges could be hazardous for the economy, but the costs could be held to a loss of 1 percent to 2 percent of GNP annually during the first decade by phasing in the charges and taking offsetting actions to mitigate the contradictory effects of the charges. Over the longer term, carbon charges of \$100 per ton could hold the level of GNP at least 1 percent lower than without the charges. To prevent growth in carbon dioxide emissions after 2000 would require even higher charges."

It points out that "the ultimate question was whether the costs imposed by carbon charges, or any other program equally effective in controlling carbon dioxide emissions, would be worth bearing in order to delay the increase in carbon dioxide concentrations." The report clearly admits that "uncertainties surrounding both the benefits and the costs of such policies make answering this question difficult."

Observing that preventive measures, including reductions in CO₂ emissions, are likely to be more effective if taken in the near term, the report states, "However, the costs of reducing the consumption of fossil energy suggest that there may be merit in looking into other ways of dealing with global warming."

The study assumes that carbon charges would be phased in over a 10 year period, beginning at \$10 per ton of carbon in 1991 and rising to \$100 per ton of carbon in 2000 (in 1988 dollars). When fully phased in, the carbon charges would amount to \$60.50 per ton of coal, \$12.99 per barrel of oil, and \$1.63 per thousand cubic feet of natural gas (mcf).

The study determines, "The direct benefits of carbon charges—slowing the growth of concentrations of greenhouse gases and delaying global warming—would probably not be felt until well into the twenty-first century."

"Industries producing steel, clay, glass, rubber, plastic, and other chemical products are relatively energy-intensive and could face reductions in size if carbon charges were imposed. In contrast, producers of foods, fibers, and other agricultural products might expand their sales because the relative prices of their products would tend to fall."

On the aggregate economic effects, the study explains that carbon charges of the size assumed for the report would have discernible effects on national income, the general level of prices, and the balance of trade. "One estimate was that the gross national product (GNP) in the year 2000 would be about 2 percent less than without the charge (2 percent of gross national product is now roughly \$100 billion). If the charge was set at \$100 per ton initially and not phased in, the immediate effect on the economy would be far more severe, possibly leading to stagnation and significant unemployment for several years."

Reviewing effects on international trade, the study forecasts that U.S. industries whose products embody—directly and indirectly—a large content of carbon-bearing fuels would lose out, while other less carbon-intensive U.S. industries competing in import or export markets could gain from the carbon charges. However, the exact effects would depend on the actions of U.S. trading partners.

The report states that U.S. action directed toward curbing CO₂ emissions may aid international efforts to reduce emissions. Yet, because the U.S. accounts for about 25 percent of world CO₂ emissions—results are "not enough to allow unilateral U.S. action to reduce global warming significantly."

Finally, the report emphasizes that global warming, if it occurred, would be a long-term problem—covering 50 years and more. "Over comparable periods, in the past, the location of economic activity has changed dramatically, new techniques of farming and new kinds of crops have come into use, and the capital stock of the nation has turned over many times....Since the economy will continue to change, more attention might be paid to creating incentives for it to change in ways that will lessen the likelihood of global warming".

The Economics of Long-Term Global Climate Change: A Preliminary Assessment

U.S. Government Interagency Task Force, Office of Policy, Planning and Analysis, U.S. Department of Energy (DOE), September 1990, Draft Report.

Key Points

- ▶ ***Global cooperation is the only means to achieve significant emission reductions without halting economic growth in some regions.***
- ▶ ***Because there is continuing disagreement over which methods are most cost-effective, additional research on economic effects and responses is still necessary.***
- ▶ ***Any mitigation policy relying on incentive-based approaches (charges, user fees, trading permits) or command-and-control techniques (efficiency standards) should minimize costs by relying on incentives to the maximum possible extent and by providing flexibility in compliance.***

This report is primarily a critical survey, not a statement of Administration or Department of Energy policy. It indicates that economic analysis of global climate change is in its infancy and advises that few assertions about costs or benefits can be made with confidence. The Task Force includes representatives from the President's Council of Economic Advisers; the Departments of State, Treasury, Commerce, Interior, Agriculture, and Energy; the Environmental Protection Agency; the Office of Management and Budget; and the Office of Science and Technology Policy.

A coordinated economic research program on global climate change, similar to that in the climate sciences, is the key proposal in this report. The three principal tasks of the research program recommended in the report would be to evaluate:

- 1) The economic effects of possible future climate change and the benefits of slowing such change;
- 2) The costs and effectiveness of various adaptive and emissions reduction measures;
- 3) The effects of such measures on U.S. and world trade and capital flows.

The report notes that most economists argue whether primary reliance should be placed on incentive-based approaches—including charges, users fees, and tradeable emissions rights—or the use of efficiency standards and other command-and-control techniques.

It explains that essentially all analysts agree that some reductions in greenhouse gas emissions could be obtained at low cost. "Disagreements focused on how fast the marginal cost of abatement rises and on how the initial, low-cost reductions could best be obtained."

The report, analyzes "planned adaptation", "unplanned adaptation", and "mitigation" policies. It declares that global action is essential if meaningful results are to be obtained without bringing economic growth to a halt in some regions. As in other regulatory arenas, mitigation policies should minimize costs by relying on incentives to the maximum possible extent and by providing flexibility. It observes that additional research is certainly necessary.

In view of scientific uncertainties on the climate change issue, the report makes the following policy approach recommendation:

"The benefits and costs of proposed policy actions should be evaluated under a broad range of outcomes that reflect the significant uncertainties that pervade the global climate issue. Flexible policies that can easily be reversed or expanded, and policies that can be justified for reasons other than climate change should be highly valued."

The report at the outset notes that there are substantial gaps in current knowledge about the economics and physical science of global climate change, and that projections for climate effects and costs in the distant future are inherently less reliable than forecasts of climate and policy costs in the short run.

It forecasts that, given projected expansion in fossil energy use throughout the world, CO₂ is expected to account for a larger share of increased radiative (greenhouse) forcing in the future than in the past. Possible climate change is not a one-gas or one-nation problem. Carbon dioxide (CO₂), chlorofluorocarbons (CFCs), methane (CH₄), and nitrous oxide (N₂O) have accounted for about 87 percent of the increase in radiative forcing in the 1980's.

The U.S. now accounts for about 21 percent of total anthropogenic CO₂ emissions, but that share is expected to shrink to around 12 percent by the middle of the next century.

The report discusses the role of new and advanced technology in reducing CO₂ emissions in the electric generation and energy end-use sectors. The report observes that of particular interest is how much could be gained by broader use of currently available technologies that enjoy only limited use because they are new and/or expensive, as well as advanced technologies that only require modest additional application.

"Advanced energy use-technology seems to have the potential to contribute significantly to reducing CO₂ emissions, but estimates of the extent of the contribution vary widely."

The report continues: "Increases in research and development budgets for end-user energy efficiency improvements and for programs that provide financial and technical assistance to

states, both of which have declined in recent years, would enhance conservation efforts. Most studies have found that the potential gains from widespread use of available 'best practice' technology are significant, possibly up to 15 percent of current consumption."

Declaring that regulatory barriers may affect the economics and introduction of some technologies, the report goes on: "At any given time, a combination of technological, behavioral, market, regulatory, and macroeconomic factors interact to determine patterns of energy use, the introduction of new technologies into widespread acceptance, and the further deployment of technologies already in use."

On electricity generation, the report calculates that by the year 2010 an estimated 400 gigawatts (GW) of new electric generating capacity may be needed to meet demand increases and to replace existing capacity that would retire. New technologies could, therefore, play a significant role in limiting CO₂ emissions from new electric capacity that will not retire until after 2010. CO₂ emissions may also be reduced as existing generating units are repowered and reboiled with more efficient technologies or with equipment designed to burn fuels with lower carbon content. The report says that the contributions from new technology to energy-efficiency gains are potentially substantial, particularly after 2010.

The report declares that global action is essential if meaningful reductions in the expected growth of any of the greenhouse gases is to be obtained without bringing economic growth to a halt.

It points out that even the total elimination of OECD emissions over the next 15 years would be insufficient to obtain a 20-percent global emissions reduction by 2005 if the former Soviet Union and Eastern Europe only stabilize emissions at their current levels and developing countries take no action to curb CO₂ emissions growth. "Global actions would also be necessary to control methane and nitrous oxide emissions, which result primarily from agricultural and energy activities." The report warns that differences in costs and benefits among nations may make it difficult to obtain global agreement on specific goals and policies. For example, countries planning to rely heavily on coal, which contains a relatively high amount of carbon per unit of energy, may have greater CO₂ emissions than countries planning to rely more on nuclear energy. "These issues will have important implications for energy security and trade balances."

The Cost of Controlling U.S. Carbon Dioxide Emissions

Dale W. Jorgenson and Peter J. Wilcoxon, Harvard University, September 1990.

Key Points

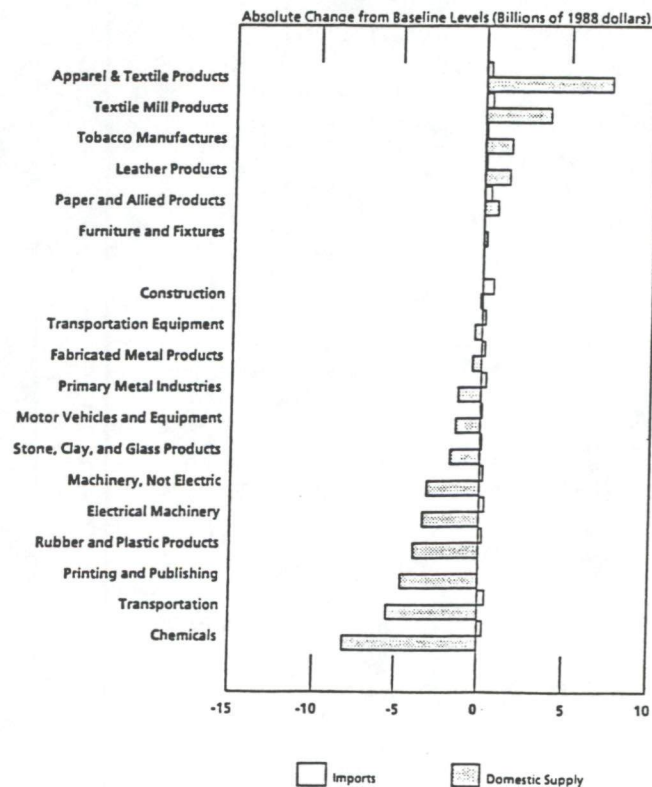
- ▶ *The principal effects of carbon control policies would be felt at the industry level, with coal mining particularly affected.*
- ▶ *The most cost-effective approach to reducing CO₂ emissions is the use of carbon taxes, while the worst approach would be an ad valorem tax on primary fuels.*

Jorgenson and Wilcoxon feel that a carbon tax to help combat global warming would have only marginal impact on U.S. GNP; although it would harm coal production considerably, causing electric utilities to switch to other fuels to keep their rates stable.

Conclusions

- ▶ The principal effects of carbon control policies would be felt at the industry level:

Effects of a \$100 per Ton Carbon Charge on
U.S. Domestic Supply and Imports, Year 2000



- ▶ Coal mining would be strongly affected by any carbon policy. Also, other energy sectors would be significantly affected if a policy other than a CO₂ tax were adopted, causing the nature of control policies (carbon, BTU, or ad valorem taxes) to be very important to energy industries.
- ▶ Even though quite large amounts of revenue are raised by the taxes, the overall effect on the economy is only the introduction of deadweight loss from the addition of a distorting tax.
- ▶ To achieve the greatest reduction in carbon emissions with the least disruption to the economy as a whole, a carbon tax would be the best instrument.
- ▶ The worst policy is clearly an ad valorem tax on primary fuels. It would increase energy prices far more than either of the other taxes to achieve a given goal.

The econometric model used by Jorgenson and Wilcoxon features disaggregation of production models for each of 35 industrial sectors (based on differences in energy intensity), and disaggregation of the household sector into 672 types of households. The model includes effects on savings and investment, and the rate of productivity growth in certain sectors. The model is based on a consistent time series of an annual interindustry transactions table for the U.S. economy covering the period 1947-1985. The report also considers the fact that a carbon tax leads to a substitution away from energy in general, and hence toward more expensive production techniques, resulting in a negative impact on the capital stock.

Three Reduction Targets

- 1) stabilizing emissions at 1990 levels
- 2) reducing emissions to 80% of 1990 levels by 2005
- 3) stabilizing emissions at 2000 levels by 2010.

Three Tax Mechanisms

- 1) A tax on the carbon content of fossil fuels
- 2) A tax on the energy content of fuels (measured in Btus)
- 3) An ad valorem tax on fuels

Each tax is applied to each target, accounting for nine simulations. The simulations are conducted over a 100 year period. In every case, the coal industry is severely affected by the taxes, mainly because of coal's high carbon content. GNP is slowed by 1% in a worst-case scenario.

The carbon tax has the least effect on GNP, causing a drop of 0.5% over a 100 year period. Annual tax revenues from this tax would be in the \$21 billion range. A Btu tax raises \$25

billion annually in revenues while cutting GNP by 0.6% over the 100 year period. An ad valorem tax produces \$54 billion annually in revenues, but raises coal prices by 29%.

The target of stabilizing emissions at 1990 levels by the year 2020 is found to be the most balanced of all the goals considered.

Jorgenson and Wilcoxon themselves note that "the principal feature of the model to which these results might be sensitive is the extent of substitutability among fuels and between fuels and other inputs in electric power generation.... they may still be too high." In other words, the authors acknowledge that they may have overestimated the degree to which (and thus underestimated the costs encountered when) electric utilities switch the fuels that are used in generation.

The Economic Effects of Restrictions on Coal and Petroleum Fuels in Stationary Uses

Report for the U.S. Department of Commerce, DRI/McGraw Hill, April 1991.

Key Points

- ▶ *All the countries involved suffer an economic loss when a multilateral strategy, using marketable permits, is used to restrict the use of coal and petroleum fuels in OECD countries.*
- ▶ *The degree of economic dislocation varies, with France suffering the least and the United States suffering the most.*
- ▶ *Among the highly industrialized countries, the factors which lessen the impacts of the restrictions are a viable nuclear option (France) and available hydropower/ natural gas (Sweden, Norway, the Netherlands).*

The objective of the study, prepared for DOC by DRI-McGraw Hill, was "to study the economic effects of a multilateral strategy to restrict the use of coal and petroleum fuels in twenty OECD countries....The strategy restricts the use of coal and oil in stationary applications at actual 1988 levels starting in 1991 and continuing through 2010." In order to analyze this restrictions policy, DRI used a program of marketable permits, in which permits to emit could be traded as long as the total emissions did not exceed the given level.

This report indicates that a multilateral approach to placing restrictions on coal and oil use results in lower GNP/GDP figures for most industrialized countries and does not stabilize CO₂ emissions.

Key Conclusions From the Scenario

- ▶ Each of the twenty countries suffers a cumulative loss in income over the twenty-year forecast period, compared with DRI's baseline expectations. But trends in GNP/GDP losses vary among countries." The United Kingdom is the hardest hit among the European nations. France experiences the smallest loss in GDP among the G-7 because of its increasing reliance on nuclear power.
- ▶ CO₂ emissions cannot be stabilized either in the OECD as a whole or any country individually. The major reason is growth in the transportation sector.

- ▶ Among the G-7, the U.S. experiences the biggest loss in cumulative GNP when both the trend and the magnitude of the loss are considered. The U.S. also contributes the largest savings in terms of absolute tons of CO₂ removed.
- ▶ Among the highly industrialized countries, the factors which lessen the impacts of the restrictions are a viable nuclear option (France) and available hydropower/natural gas (Sweden, Norway, the Netherlands).
- ▶ Essentially all energy prices go up in order to make up for coal and oil restrictions. Much more natural gas will be used, and its price will reflect that lack of energy alternatives. In addition, using natural gas as a substitute puts back into the air 60% of the CO₂ content of a ton of coal and 76% of the CO₂ content of a ton of oil.

The Department of Commerce report also points out the significance of distinguishing the trend—whether cumulative impacts of the restrictions are growing or shrinking over time. The U.S. and Japan are cited because their loss of cumulative GNP over the twenty years would be the same (0.9%), even though the U.S. has a tougher time with restrictions after 2000 (due to an increase in stationary coal consumption). Japan would enter into a near recession during the first part of the restrictions (beginning in 1991) because of previous economic growth.

Limiting Net Greenhouse Gas Emissions in the United States: Report to the Congress of the United States

U.S. Department of Energy, Office of Environmental Analysis, Deputy Under Secretary for Policy, Planning and Analysis, September 1991.

Key Points

- ▶ ***A comprehensive approach to limiting net greenhouse gas emissions is likely to be the most effective.***
- ▶ ***After analyzing various types of policy options, including carbon taxes, the Department of Energy concludes in this report that the Bush Administration's National Energy Strategy (NES) actions would stabilize energy-related emissions of greenhouse gases.***
- ▶ ***The NES actions are effective because they are a comprehensive package whose benefits exceed costs. This report also finds that advanced technology plays a very important role in emissions reduction.***

This report confirms the DOE belief that significant CO₂ reductions will be extremely expensive unless Congress enacts the Bush Administration's National Energy Strategy.

The report was prepared in response to a request from Congress for an analysis of options that would keep national CO₂ emissions 20% below 1990 levels by the year 2000 and 50% below 1990 levels by 2010.

Volume I of the report focuses on energy technologies, and finds that "changes in the way energy is used in the U.S. economy, along with changes in land use, can significantly affect the growth rate of net U.S. emissions. Development and use of low-emission energy and environmental technologies are essential to provide the mechanisms for such changes."

Volume I examines a wide range of technologies and their performances and costs. The report finds that "advanced technologies are essential for the four main strategies available to cut energy related emissions". These strategies are:

- 1) fuel substitution (substituting low-carbon for high-carbon fuels)
- 2) carbon removal (extracting carbon from fuel or waste streams either before or after fossil fuel combustion)
- 3) energy efficiency improvement
- 4) energy service demand modifications

The report points out, however, that "the role of advanced technologies is affected substantially by behavioral and structural changes in the economy that are not currently well understood." The report also finds that the time needed to achieve results from these technologies varies greatly, and in some cases a substantial time period is required. Also, there are significant uncertainties regarding performances and costs for technologies that are not yet in commercial use.

Volume II of the report focuses on energy responses and analyzes various energy policies that could affect greenhouse gas emissions. The report examines a variety of policy options, including National Energy Strategy (NES) actions, which include CFC reductions, tree planting, energy efficiency measures, and increases in energy production from nuclear and renewable sources. The report also examines measures that go beyond the NES, including carbon taxes and emissions caps achieved through the use of tradeable permits. The report finds that:

- 1) "Taking a comprehensive approach to the analysis of U.S. contribution to global warming potential seems preferable to focusing on either a single greenhouse gas, such as CO₂, or a single human activity, such as energy production and use."
- 2) The Bush Administration's NES actions would hold energy-related emissions of greenhouse gases "at or below 1990 levels throughout the period to 2030". This represents a reduction of more than 40% relative to the base case. The NES actions are effective because they are a comprehensive package whose benefits exceed costs.
- 3) The goals of reducing CO₂ emissions 20% by 2000 and 50% by 2030 from 1990 levels are technically possible, but have high costs. These goals would require actions that go beyond the NES, and would be subject to diminishing marginal returns.
- 4) It would cost between \$34 billion and \$53 billion per year by 2030 to achieve a 50% CO₂ reduction requirement, assuming all the administration's NES proposals are enacted into law and an aggressive afforestation program is initiated. The same reduction without the nuclear provisions in the NES would cost an estimated \$104 billion a year.
- 5) Relying on taxes alone, it would cost roughly \$95 billion a year to cap U.S. CO₂ emissions in 2000 at 20% of their 1990 level. It would be impossible to achieve a 50% reduction in CO₂ emissions relying solely on taxes.

- 6) Pursuing an aggressive tree planting program in addition to the provisions in the NES could significantly reduce the costs of any emissions reduction requirement. Specifically, a 20% CO₂ reduction could be achieved by 2000 for between \$9 billion and \$14 billion a year. With the tree program, this reduction would only require a tax of between \$28 and \$42 per metric ton of carbon.
- 7) "The United States acting alone cannot hold global greenhouse gas or carbon emissions constant. Even the most extraordinary efforts of the entire OECD acting alone could not hold global fossil fuel carbon emissions constant beyond the year 2020. By the year 2020, non-OECD fossil fuel carbon emissions are expected to exceed present global emissions."

Assessment of Greenhouse Gas Emissions Policies on the Electric Utility Industry: Costs, Impacts, and Opportunities

ICF Resources Inc., prepared for Edison Electric Institute, November 1991.

Key Points

- ▶ ***Command-and-control reduction policies cause tremendous costs to utilities, their customers, and the economy as a whole.***
- ▶ ***Better options include regulatory incentives to encourage utilities to adopt conservation and demand-side management programs; programs to encourage the development of reliable, low-cost renewables; reform of nuclear licensing procedures; and incentives to replace existing capacity with new more efficient units.***

This report, prepared by ICF Resources for Edison Electric Institute, assesses the costs and impacts of greenhouse gas emissions policies on the electric utility industry. It considers changes in emissions, costs of compliance, changes in electricity demand, and changes in capacity mix and fuel use. Only CO₂ emissions are considered because of the report's electric utility focus.

The report considers four greenhouse gas policies (three levels of command-and-control reductions and a carbon tax), compared to a base case of no emissions policies. In the base case, CO₂ emissions are expected to increase at a rate of 1.4%-2.7% per year as a result of growth in demand for electricity.

The report finds that "important policies may include regulatory incentives to encourage utilities to adopt conservation and demand-side management programs; programs to encourage the development of reliable, low-cost renewables; reform of nuclear licensing procedures; and incentives to replace existing capacity with new more efficient units."

Predictions of command-and-control emissions stabilization or reduction scenarios:

- ▶ Costs to electric utilities and their customers range from as much as \$24 billion (for stabilization) to as much as \$52 billion (for a 20% reduction) in the year 2005. These costs rise substantially by 2015.
- ▶ There is a large shift away from coal-fired generation, and there is a shift to gas-fired generation. As a result, natural gas prices rise sharply. The availability of nuclear power and renewable resources is critically important.

- ▶ Electricity prices rise by as high as 30% by 2015, which causes price-driven reductions in demand of about 10%.

The report makes the following recommendations for a viable set of policy actions to decrease emissions in a cost-effective manner and ease the burden of any greenhouse gas policies that may be considered in the future:

- ▶ "...reasonably priced nuclear power would have substantial value in reducing greenhouse gas emissions. Therefore, the costs of complying with carbon policies would be heavily influenced by policies that facilitate the availability of nuclear power."
- ▶ "Significant investment in the development and demonstration of renewable technologies may be required."

In terms of carbon taxes, the report concludes that:

- ▶ Compliance costs for electric utilities and their customers range from \$68 billion to \$76 billion in 2005, increasing to \$78 billion to \$108 billion by 2015. This cost includes the cost of the tax, the incremental cost of utility operations, and the cost of demand reductions valued at the price of electricity to customers.
- ▶ "The cost of a carbon tax to the electric utility sector is high relative to the level of emission reductions achieved. Moreover, the carbon tax analyzed here has substantial effects on electricity rates, thereby prompting price-induced consumer reductions in electricity use."
- ▶ "Carbon taxes generally have a less dramatic effect on utility capacity expansion and dispatch decisions than do emissions restriction policies, because beyond a certain level, it is less expensive, from the point of view of the utility and its customers, to pay the tax, rather than reduce emissions further."
- ▶ Revenues from a carbon tax would be large, and could be used for investment, research and development, reduction of other taxes, or reduction of the deficit. However, the revenue effects of the tax depend on accompanying fiscal, monetary, and other policies.

The study also notes that there are opportunities to reduce greenhouse gas emissions in other sectors, including electrification of the transportation sector, reforestation, and greenhouse gas recovery.

The Cost of Controlling Carbon Dioxide Emissions

W. David Montgomery, Charles River Associates Incorporated, December 1991.

Key Points

- ▶ ***The target of achieving emissions of 80% of their 1988 level by the year 2000 would require a carbon tax of \$200 per ton or more, and would produce annual losses of 1.7 percent of GNP in 2020, increasing to 2.4 percent in 2100.***
- ▶ ***The economic benefits of ameliorating global climate change might not appear until the end of the next century and could amount to no more than 0.5 percent of GNP.***

This report describes key economic models and their predictions regarding CO₂ taxes. These models attempt to predict the level of carbon tax needed and the resulting effects on GNP for the target of achieving emissions of 80% of their 1988 level by the year 2000 or 2010 and holding emissions at that level indefinitely. Combined results from these models lead Montgomery to conclude that:

- ▶ The target would require a carbon tax of \$200 per ton or more, and would produce annual losses of 1.7 percent of GNP in 2020, increasing to 2.4 percent in 2100.
- ▶ A \$200/ton carbon tax amounts to about \$120/ton of coal, \$26/barrel of oil, and \$3.20/thousand cubic feet (mcf) of natural gas. Were these taxes levied in 1991, the GNP loss would be about \$95 billion.
- ▶ The economic benefits of ameliorating global climate change might not appear until the end of the next century and could amount to no more than 0.5 percent of GNP.

Models

- 1) ***Global 2100***, Manne (Stanford) and Richels (Electric Power Research Institute)
- 2) ***Jorgenson-Wilcoxon***, Jorgenson (Harvard) and Wilcoxon (University of Texas at Austin)
- 3) ***Edmonds-Reilly***, Edmonds and Reilly (Oak Ridge Associated Universities; Pacific Northwest Laboratory)
- 4) ***DRI***, Data Resources, Inc.

Montgomery finds the following conclusions from each of the models:

**Comparison of Model Results,
Assuming Stabilization at 80 Percent of 1988 Emissions**

	Global 2100		Jorgenson- Wilcoxon	Edmonds- Reilly		DFI
Year	2020	2100	2020	2020	2100	2020
Baseline Emissions (billion tons carbon)	2	4.5	1.6	1.7	2.7	1.7
Baseline GNP (trillion 1990\$)	10.4	30	8.5	11.5	32.6	9.9
Target Emissions (billion tons carbon)	1.1	1.1	1.1	1.1	1.1	1.1
Tax Required (1990\$ per ton carbon)	\$369	\$208	\$60	\$220	\$550	\$427
GNP loss (billion 1990\$)	\$230	\$750	\$150	\$150	\$750	\$180
Percent Reduction in Emissions from Baseline	-45%	-76%	-31.6%	-35%	-59%	-37%
Percent GNP Loss	-2.2%	-2.5%	-1.6%	-1.3%	-2.3%	-1.8%

Description of Models According to Montgomery

The *Global 2100* model covers the time period from 1990-2100. It covers the world, divided into 5 regions, and features a long-term model with constraints on resources and technology introduction. In this model, a fairly high level of taxes (\$208 per ton of carbon) is needed to achieve the emissions reduction, because the technology of electricity generation is explicitly represented, making the assumption that substitution among types of energy is more difficult. The model also places a constraint on natural gas supplies and assumes that new energy technologies that can allow the use of low-carbon or carbon-free energy (like nuclear) may not be available on a wide scale. For this reason, reductions in emissions must come from lower energy use.

By the year 2100, however, it is assumed that a carbon-free energy technology is available that is able to provide unlimited quantities of carbon-free energy. This assumption is made based on the idea that a \$208 per ton carbon tax will bring out the need for such technology.

Montgomery finds that, though this model has a fairly sophisticated view of the difficulties of fuel-switching, it tends to have very simple depictions of energy use itself and of the economic impacts of higher energy costs.

The *Jorgenson-Wilcoxon* model covers the time period of 1990-2030. It covers the U.S. only, and features a more sophisticated economic model with a detailed structure of industry and capital formation.

This model assumes that full employment is always maintained and that the entire capital stock is perfectly mobile and able to work with any mixture of fuels. Because of this, the Montgomery report finds that the model is not well-suited to show the short-term consequences of a tax, and it severely underestimates the very important costs during the transition period in which adjustments to the tax are being made, and hence also severely underestimates the tax rate necessary to achieve the desired emissions reductions. Because of the assumption that the capital stock is perfectly mobile, the model exaggerates the effect of an energy tax on emissions; in reality, there are greater costs associated with switching, and a larger tax would be needed to entice an electricity producer to switch fuels.

Also, the model assumes no limits on natural gas resources, so it is likely to underestimate how large a tax would be required to achieve stable emissions, especially in later years.

Despite its long-run focus, Montgomery seems to feel that Jorgenson-Wilcoxon has a very sophisticated representation of the economy, and that, in this respect, it is probably the most reliable of the models. Although this model predicts a relatively low overall decline in GNP, it predicts a relatively large loss in GNP per unit of carbon tax. It also considers an effect which is not considered in any other model: it shows that an increase in energy prices caused by a carbon tax makes capital goods more expensive, and thus causes investment to be more costly (a given dollar volume of investment will purchase less plant and equipment). Thus, investment is depressed, which leads to a slowing in the rate of growth of the economy, and can add up to a large loss of GNP over time.

Montgomery notes that if Jorgenson-Wilcoxon had used the tax level found to be necessary in the Global 2100 model (\$208 per ton of carbon), the loss in GNP might be as high as 5.6 percent.

The *Edmonds-Reilly* model covers the years 1990-2100. It covers the world, divided into 9 regions, and features a consideration of world energy markets, but has simple demand and economic linkages.

According to Montgomery, this model is well suited for analyzing the long-run. It depicts international energy trade, and shows supply constraints on oil and gas. It also gives a detailed account of the introduction of new technologies with standard supply curves. Unlike the Global 2100 model, this model assumes no backstop technology, forcing taxes to have to

rise over time to maintain the emissions target. This model, however, is found to have highly simplified depictions of energy use and of the economic impacts of higher energy costs.

The *DRI* model covers the time period of 1990-2020 in the U.S. and 12 OECD countries. It features integrated models of macroeconomic cycles and long-run energy supply and demand.

In this model, CO₂ emissions respond less strongly to carbon taxes than in the other three models. Depending on different assumptions about the responses of trade and U.S. monetary policy, this model shows either the largest or the smallest damage on GNP per dollar tax.

According to Montgomery, this model contains a more complete representation of savings and investment than do the other models. It highlights the transition costs of the shock of an energy tax. The DRI model finds rapid reductions in energy use to be difficult, leading to the need for a high tax.

The model also attempts to show the revenue effects from the tax, predicting that if revenues are used to reduce the deficit, interest rates would decline enough to increase investment significantly, leading to economic growth. Because of this, by 2010 the economy would be just as well off as it would have in the absence of this tax. However, Montgomery makes the important point that tax analysts warn of assuming that any individual measure, without concerted effort, would have the broad economic benefit of reducing the deficit.

SCIENCE

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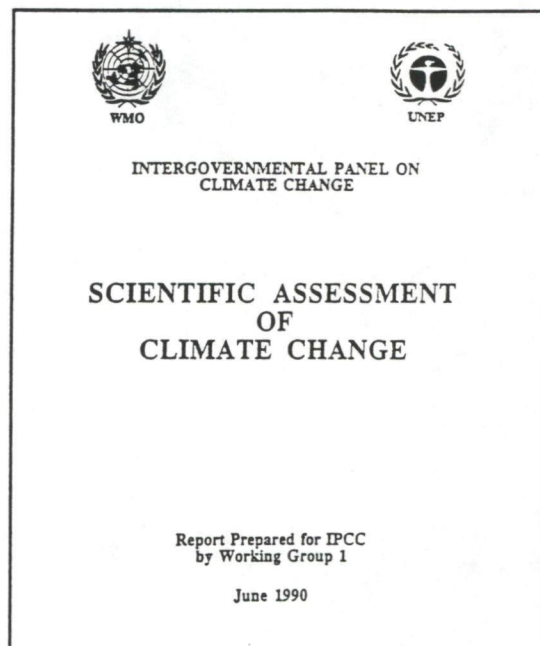
1. *The Potential Effects of Global Climate Change on the United States*, United States Environmental Protection Agency, December, 1989.
2. Meier, Mark F., *Role of Land Ice in Present and Future Sea Level Change*, National Research Council, 1990.
3. *The Scientific Assessment of Climate Change*, The Intergovernmental Panel on Climate Change, August 1990.
4. *Policy Implications of Greenhouse Warming*, National Academy of Sciences, April 1991.
5. Idso, Sherwood, *Testimony before The California Energy Resources and Conservation Development Commission*, November 19, 1991
6. Karl, Thomas, *Global Warming: Evidence for Asymmetric Diurnal Temperature Change*, National Oceanic and Atmospheric Administration, 1991.
7. Michaels, Patrick, *Testimony before the California Energy Commission*, 1991.

What Is Known About Climate Change Science

Overview

There are no empirical findings upon which to conclude that increases in CO₂ and other greenhouse gas emissions will precipitate changes in world climate. Even if there were scientific confirmation that an increase in CO₂ and other greenhouse gas emissions would lead to an increase in mean global temperatures, such an increase may well be within the limits of historic variations, and hence not require drastic action. Natural events, such as solar activity, volcanic eruptions, and ocean current patterns, may all be more dominant elements in determining climate.

In June 1990, Working Group One of the U.N.-sponsored Intergovernmental Panel on Climate Change (IPCC)¹ issued a scientific report, on which some governments base their conclusion that immediate action to reduce CO₂ emissions is warranted. The report was adopted in August, 1990. Since that time, many of the conclusions in the summary of the report have been criticized by scientists who suggest that the General Circulation Models (GCMs) used as evidence for the IPCC's conclusions are too primitive to be the basis for policy decisions. Some scientists have stressed the widely divergent results of such models, and note their failure to portray the response of feedback mechanisms to any initial atmospheric warming. Scientists have warned that "policymakers would be wise to invest in the additional resources needed to improve the reliability of greenhouse forecasts before undertaking corrective programs that could turn out to be unnecessary."² Many scientists do not believe a catastrophic climate change is on the horizon.³



S. Fred Singer of the University of Virginia recently surveyed a group of scientists, many of whom contributed to the IPCC report. The survey concludes that there is no consensus on the climate change issue.⁴ And in a *Wall Street Journal* article, Singer noted that the IPCC report ignores a number of valid scientific objections to the theoretical calculations that predict a global warming.⁵

Climate Models

General Circulation Models: The National Academy of Sciences (NAS) stresses that existing computerized GCMs do not provide a reliable picture of future climate change scenarios because they only model the atmosphere and do not fully take feedbacks into account. In an April 1991 report, the NAS concluded that, although computer simulations using GCMs are considered the best available tools for predicting climate change, they lack adequately validated representations of factors such as cloud cover feedback, ocean circulation, and hydrologic interactions.⁶ As stated in their report, "Neither the available climate record nor the limited capabilities of the climate models permit a reliable forecast of the implications of continued accumulations of greenhouse gases in the atmosphere." They add, "For the purposes of informed policy choice, it is crucial to acknowledge the limited capability of the GCMs."⁷

In addition, the IPCC itself notes, "The validation of a number of atmospheric model variables has been handicapped by limitations in the available observed and model data."⁸ Patrick Michaels of the University of Virginia adds, "...it is indefensible to use GCMs as a basis for any expensive energy policies. The use of knowingly incorrect parameters...should easily be enough to discredit GCMs as vehicles for policy."⁹

He is confident that the majority of the scientific community believes that GCMs are flawed. He adds that current generation GCMs "have overestimated warming by a factor of between two and four. Further, the observed character of climate change in the face of the greenhouse enhancement has been to primarily warm winter nights, and to cool summer days. The scenarios of great cost to society are predicated upon the opposite of what has occurred."¹⁰

Climate Change Concerns

Temperature: One of the key conclusions from the IPCC scientific report is that "it is not possible to attribute all, or even a large part of the global-mean warming to the enhanced greenhouse effect on the basis of observational data currently available."¹¹ While it is true that there has been a marginal increase in *land-based* temperatures since the mid-1970's, there have been more extreme rises and decreases in the past. Supporting this point, Roy Spencer of the National Aeronautics and Space Administration's (NASA) Marshall Space Flight Center and John Christy of the University of Alabama, while working to determine the reliability of long-term climate models, concluded that the *atmospheric* temperature record from 1979 through late 1988 showed no significant global trend. Spencer and Christy's conclusions were reached using definitive measurements from NASA weather satellites. As the analysis continued into 1989, similar results were reported.¹²

Thomas Karl of the National Oceanic and Atmospheric Administration (NOAA) recently updated his research on year-month mean maximum and minimum surface thermometric records, finding that "most of the warming which has occurred in [the U.S., USSR, and

China] over the past four decades can be attributed to an increase of mean minimum (mostly nighttime) temperatures. Mean maximum (mostly daytime) temperatures display little or no warming."¹³ Nighttime warming scenarios may impact future climate trends positively. Michaels notes that nighttime warming may create "the prospect of longer growing seasons, and substantially warmed winters with little change in summer extreme temperatures."¹⁴

Michaels, speaking of the "urban heat island effect," notes that "taking the Earth's temperature from ground-based thermometers is a daunting proposition, owing to the fact that cities tend to grow up around (and artificially warm) their weather stations, and because the site selections for those very stations is climatically non-random. These factors induce systematic errors or biases into the temperature records."¹⁵

Richard Lindzen, Sloan Professor of Meteorology at the Massachusetts Institute of Technology, concludes that, "Despite popular opinion to the contrary, the quantitative expectation of substantial global warming (more than 1° C or so) arising in the next century because of man's production of minor greenhouse gases (CO₂, chlorofluorocarbons [CFCs], methane, etc.) is without substantive scientific foundation."¹⁶

Sea Level Rise: While some scientists believe that significant sea level rise would accompany global warming, the IPCC notes that, "there is no firm evidence of an acceleration in global mean sea level rise over this century,"¹⁷ perhaps indicating that predictions of a global warming trend are incorrect. David Aubrey of the Woods Hole Oceanographic Institution stresses that, until more is known about the driving forces behind climate change, it makes no sense to try to predict such "second order" effects as sea level rise.¹⁸ While some claim that rising air temperatures may cause increasing snow and ice melting—leading to sea level rise—data also suggests that a rise in CO₂ concentrations may lead to increased snow precipitation in Antarctica, which would have the opposite effect on sea level, possibly causing it to fall by 0.1 to 0.5 meters in the next 100 years.¹⁹

The authors of the NAS report dismiss the ice-melting scenarios as "virtually impossible by the end of the next century" and choose instead to concentrate on thermal expansion (and contraction) of the oceans, which is caused by a combination of increasing (decreasing) temperature and salinity. While a thermal expansion of the world's oceans is more plausible than the melting of ice sheets, such changes "are not large enough...to account for the differences over tens of thousands of years," according to NAS.

Desertification: The potential for mass destruction of the world's forests and an increase in desert area have been highlighted as two of the more severe impacts that could accompany changes in climate. Recent evidence suggests, however, that increasing atmospheric CO₂ levels may actually lead to accelerated forest growth and decreasing desertification. Sherwood Idso of the U.S. Agricultural Research Service maintains that, as the air's CO₂ content continues to rise, "Natural ecosystems will [benefit], as Earth's more robust vegetation grows more vigorously and wins back great tracts of land previously lost to

desertification. Grasslands will flourish where deserts now lie barren...and forests will make a dramatic comeback to reclaim many areas presently sustaining only brush and scattered shrubs."²⁰

Other Possible Causes of Climate Change

Solar Variations: Small variations in solar radiation may cause climate changes as large as those that some believe would be caused by large increases in greenhouse gases. Precise observations of the sun's activity have been taken only for the past decade, and future solar variations could be extremely large.²¹ In November 1991, two Danish geophysicists announced a close statistical correlation between variations in the length of the sunspot cycle and fluctuations in the world's surface temperature over the last 130 years. Analyzing lengths of sunspot cycles, which averaged 11 years, they found that variations in cycle length matched almost perfectly the fluctuations in northern-hemisphere temperatures from the mid-1850s to the mid-1980s. This suggests that temperature records could correlate more closely with solar variation than with changes in the concentration of greenhouse gases.²²

Additional Factors: Major natural events such as volcanic eruptions, as well as long-term changes in land-use trends can also have significant impacts on climate. Changing ocean current patterns, for example El Niño and La Niña, are capable of setting off chains of events that can affect the weather in many parts of the world. In 1982-83, higher-than-average sea-surface temperatures pumped massive amounts of energy into the atmosphere, bringing on a climatic chain reaction responsible for disastrous drought conditions in some parts of the world and flooding rains in others.²³

Other Considerations

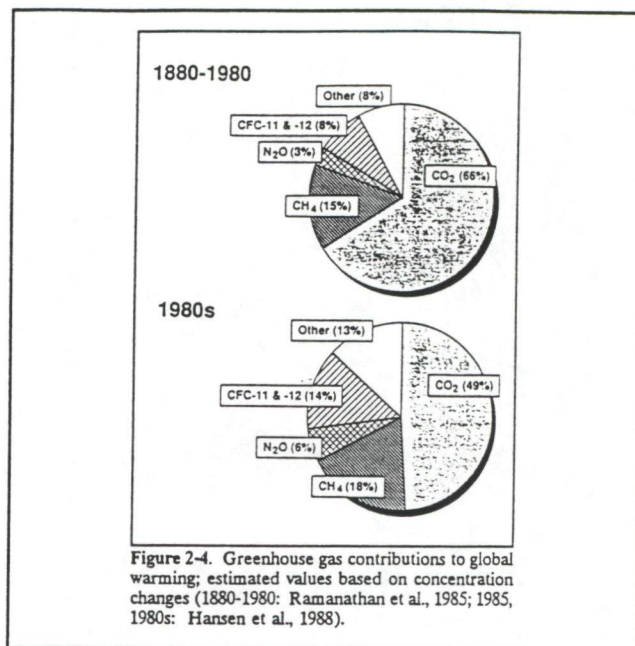
Greenhouse Gases: While CO₂ garners most of the public attention because man-made sources of it can be more easily identified,²⁴ other gases have more potent greenhouse radiative "forcings" that hold more of the Earth's heat.²⁵ Although methane (CH₄) has a lower atmospheric concentration than CO₂, its climate forcing effect is much greater than that of CO₂.²⁶ The global warming potentials (GWP)²⁷ of various greenhouse gases, relative to CO₂, over a 20 year time period, are as follows (CO₂'s GWP is listed as 1): methane 63, nitrous oxide 270, and CFC-11 4500. In addition, the production of tropospheric ozone as a result of emissions of methane leads to a large indirect forcing effect. The GWP of the tropospheric ozone created as a result of methane release is 24.²⁸ Therefore, it is necessary to have a comprehensive understanding of the interactions among these greenhouse gases and their relative impacts prior to designing actions to reduce emissions.²⁹

Deforestation and Wood Use: Forests are one of the largest carbon "sinks",³⁰ containing about 60% of the organic carbon stored on world land surfaces. Destruction of the world's forests, particularly in South America, reduces natural CO₂ absorption. Slash-and-burn agriculture, common in developing countries, releases even more CO₂ into the atmosphere.

Furthermore, in those countries where wood is still a primary fuel for cooking and heating, inefficient combustion is a significant factor. Deforestation alone contributes a net equivalent of 50% of the annual total input of CO₂ to the atmosphere from fossil fuel combustion.³¹

Population Growth: Although developing countries currently account for only one-fourth of world greenhouse gas emissions, as they industrialize and their energy demand increases in relation to their rapidly growing populations, they are projected to surpass the more developed countries in emissions of CO₂ and other greenhouse gases. According to Karl Gawell of Zero Population Growth, between now and 2030, the population added in developing countries will contribute twice the CO₂ emissions as the population added in the industrialized world.³²

Positive Effects of Increasing CO₂: While proponents of the "popular vision" that a catastrophic climate change is at hand insist that increased CO₂ concentrations in the atmosphere carry only negative effects, evidence to the contrary continues to emerge. Sherwood Idso of the Agricultural Research Service and other researchers have shown that, under certain limits, plants function much better when exposed to increased levels of CO₂. Even in situations where water or nutrients are limited, agricultural research has demonstrated that the relative growth enhancement for plants due to CO₂ enrichment is great. Plants respond even better to CO₂ enrichment at higher temperatures. The NAS notes, "An increasing atmospheric concentration of CO₂ would increase agricultural production by enhancing the use of sunlight and slowing transpiration in some plants."³³



1. Intergovernmental Panel on Climate Change (IPCC), Working Group One, *Scientific Assessment of Climate Change*, June 1990.
2. George C. Marshall Institute, *Scientific Perspectives on the Greenhouse Problem*, 1989.
3. Michaels, Patrick, "Greenhouse Disaster," Summary of remarks submitted to *Science*, September 28, 1990.
4. Singer, S. Fred and Jay S. Winston, *Singer-Winston Survey of IPCC Reviewers*, October 1991.
5. S. Fred Singer, "No Scientific Consensus on Greenhouse Warming," *Wall Street Journal*, September 23, 1991.
6. Op. cit., NAS, *Policy Implications*.
7. Ibid.
8. Op. Cit., IPCC, *Scientific Assessment*. Also, from U.S. Environmental Protection Agency, *Policy Options for Stabilizing Global Climate*, December 1990, "...the simplified atmospheric chemistry and ocean models employed [in the study of climate change] may not adequately reflect the underlying processes..."
9. Michaels, Patrick, Statement before the California Energy Commission, 1991.
10. Op. cit., Michaels
11. Op. cit., IPCC, *Scientific Assessment*.
12. Spencer, Roy, "Precise Measurements of Global Temperature Trends from Satellites," *Science*, March 30, 1990.
13. Karl, Thomas, *Global Warming: Evidence for Asymmetric Diurnal Temperature Change*, National Oceanic and Atmospheric Administration, 1991.
14. Op. Cit., Michaels.
15. Op. cit., Michaels, Testimony before the California Energy Commission.
16. Lindzen, Richard S., Massachusetts Institute of Technology, Statement to the House Committee on Science, Space and Technology, October 8, 1991.
17. Op. cit., IPCC, *Scientific Assessment*.
18. Conversation with David Aubrey, January 15, 1992.
19. Meier, Mark F., *Role of Land Ice in Present and Future Sea Level Change*, University of Colorado, 1990. Also from Stevens, William K., "Scientists Suggest Global Warming Could Hasten the Next Ice Age," *New York Times*, January 21, 1992, a January 1992 study by Canadian and American scientists strengthens this argument. Gifford Miller of the University of Colorado and Anne de Vernal of the University of Quebec at Montreal concluded that if global warming proceeds as some have forecast, the Northern Hemisphere's ice sheets could expand as much as they did at the start of the last Ice Age (when the world's climate was warmer than it is today). After reconstructing conditions at the start of the last glaciation 122,000 years ago, Miller and de Vernal

concluded that a global warming would cause more sea-water to evaporate, producing moisture for increased precipitation in the winter. Such precipitation would fall as snow, in turn compressing into ice.

20. Idso, Sherwood, Testimony before the California Energy Commission, November 19, 1991.

21. U.S. Environmental Protection Agency, *The Potential Effects of Global Climate Change on the United States*, December 1989.

22. *Science*, November 1991. Analysis by Dr. Eigil Friis-Christensen and Dr. Knud Lassen of the Danish Meteorological Institute in Copenhagen.

23. Stevens, William K., "Earth's Temperature Has Dropped a Little After a Warm Spell," *New York Times*, December 24, 1991.

24. Recently, the Worldwatch Institute reported that CO₂ emissions have actually decreased over the last two years, with indications that they may decrease further in 1992. Although CO₂ levels are generally expected to increase over time, the increase may not be consistent. Press Release, Worldwatch Institute, December 1991.

25. Op. cit., IPCC, *Scientific Assessment*. The climate of the Earth is affected by changes in radiative forcing due to several sources (known as radiative forcing agents). Such sources include the concentration of radiatively active (greenhouse) gases, solar radiation, aerosols, and albedo. "For the period 1765 to 1990, CO₂ has contributed about 61% of the forcing, methane 17% plus 6% from stratospheric water vapor, N₂O 4% and the CFCs 12%. For the decade 1980 to 1990, about 56% of the forcing has been due to changes in CO₂, 11% due to the direct effects of [methane] CH₄ and 4% via stratospheric water vapor, 6% from N₂O and 24% from the CFCs."

26. Craig, H. and C.C. Chou, *Geophysics Research Letter* 9, 1982.

27. Op. cit., IPCC, *Scientific Assessment*. "GWP" is an index which allows the climate effects of the emissions of greenhouse gases to be compared. The GWP depends on the position and strength of the absorption bands of the gas, its lifetime in the atmosphere, its molecular weight and the time period over which the climate effects are of concern.

28. Op. cit., IPCC, *Scientific Assessment*.

29. Op. cit., Gray.

30. A "sink" is a natural absorption mechanism which removes a gas from the atmosphere.

31. Sullivan, K.M., *The Effect of CO₂ Emissions from Coal Fired Power Plants*, The World Coal Institute, July 1989.

32. Carr, R., *Population as a Cause of Global Warming*.

33. Op. cit., NAS, *Policy Implications*.

The Potential Effects of Global Climate Change on the United States

United States Environmental Protection Agency, December, 1989.

Key Points

- ▶ *Greenhouse Gases: "The concentration of a number of trace gases in the atmosphere is increasing as a result of human activities."*
- ▶ *Solar Variations: "Small variations in solar radiation have the potential for causing climate changes as large as those caused by projected increases of greenhouse gases."*
- ▶ *Climate Feedbacks: "Although important climate feedback mechanisms have been identified, we may not understand or even know about all the mechanisms involved in climate feedbacks."*
- ▶ *Clouds: "It is not possible to be certain of the net effect of cloud feedbacks because of the complexity of clouds and their response to climate change."*
- ▶ *"Unforeseen climate events may be possible in the future and [until] the ocean response is well understood, the timing and amplitude of the climatic response to increased greenhouse gases and other forcings will need to remain the subject of additional research."*

This report was written in response to a congressional request in Fiscal Year 1987. It focuses on the health and environmental effects of climate change. Chapter 2 focuses on the science of climate change. Key conclusions from Chapter 2 follow:

Climate Forcings

Greenhouse Gases: "The concentration of a number of trace gases in the atmosphere is increasing as a result of human activities."

Although CO₂ concentration in the atmosphere exceeds other greenhouse gases, other gases have more potent forcings. For example, even though methane has a lower atmospheric concentration than CO₂, its forcing is significantly stronger. EPA notes, "Although methane has a much lower atmospheric concentration than CO₂, it is more effective at dirtying the atmospheric window and accounts for about 18% of current anthropogenic greenhouse forcing."

Solar Variations: "Small variations in solar radiation have the potential for causing climate changes as large as those caused by projected increases of greenhouse gases....Since [high-quality measurements] have been taken only for a short period, they do not rule out past or future variations of the sun that would be larger.

Volcanoes: "Large volcanoes can significantly increase the concentration of stratospheric aerosols, decreasing the amount of sunlight reaching the surface and reducing surface temperatures by several tenths of degrees for several years. Because of the thermal inertia of the climate system, volcanoes can even be responsible for climate changes over decades."

Climate Feedbacks

"Although important climate feedback mechanisms have been identified, we may not understand or even know about all the mechanisms involved in climate feedbacks."

Clouds: "Clouds respond directly and immediately to changes in climate and may represent the most important uncertainty in determining the sensitivity of the climate system to the buildup of greenhouse gases....At the present time, clouds have a large greenhouse effect, but this is offset by their even stronger cooling effect, because clouds reflect sunlight back to space. Since the current greenhouse effect of clouds is larger than the effect of an increase of CO₂ by a factor of 100, small changes in clouds as climate changes can be very important in affecting the overall climate response to increases in trace gases....It is not possible to be certain of the net effect of cloud feedbacks because of the complexity of clouds and their response to climate change."

Oceans: "Oceans play an important role in the climate response to changed forcings because they absorb and emit both heat and CO₂, and because changing ocean circulation can change the redistribution of energy internal to the climate system....Oceans are also the dominant sink of atmospheric CO₂, absorbing about half of all CO₂ that is put into the atmosphere each year by the combustion of fossil fuels and deforestation....unforeseen climate events may be possible in the future and [until] the ocean response is well understood, the timing and amplitude of the climatic response to increased greenhouse gases and other forcings will need to remain the subject of additional research."

Observational Evidence of Climate Change: "Thermometers have been used to actually measure global climate change for more than 100 years in enough locations to provide an estimate of how the planet's climate has changed during this period....Problems common to [data sets] include possible contamination from urban heat islands, inadequate spatial coverage of the Earth, and corrections necessary to counteract the effects of changing the methods used to take observations from ships....While the gradual global warming seen during the past century is consistent with the increasing greenhouse gases during this period, most scientists suggest that a clear link has not yet been established between observed temperatures and the greenhouse effect."

General Circulation Models: Computer speed and size constraints limit the size of grid boxes on the GCMs to 150 to 600 mile areas. "Thus, in one of these grid boxes, all the complexity of weather and horizontal variation is reduced to one number for temperature, one for cloudiness, and so forth. The equations used to represent the physical and chemical processes involved are also simplifications of real-world processes....although the actual model projections can **not** be taken as predictions of the future, they are useful in providing scenarios for impact assessment."

Role of Land Ice in Present and Future Sea-Level Change

Mark F. Meier, University of Colorado, excerpted from National Research Council, Sea Level Change, 1990.

Key Points

- ▶ *Meier writes that the increase in air temperature caused by a rise in concentration of CO₂ may cause increased snow and ice melting, and some of this meltwater may run off to the oceans, causing a rise in sea level....On the other hand, a rise in CO₂ concentration may, in some regions, lead to increased snow precipitation on glaciers and ice sheets, which will have the opposite effect on sea level.*
- ▶ *Predicting the effects of climate change on ice growth and wastage is a complex problem because several different, interacting processes must be considered.*
- ▶ *Most of the Antarctic Ice Sheet and much of the Greenland Ice Sheet are not likely to be affected by small rises in air temperature, such as those that might be caused by an increased CO₂ concentration in the next century. Increases in summer air temperature cause no melting unless the increases exceed the present (negative) surface air temperature.*
- ▶ *Calving icebergs (icebergs which break off of others) could respond to slight increases of melting and rainfall by rapid and dramatic disintegration, but it is difficult to calculate the rate of change because of our insufficient knowledge of subglacial hydraulics, basal sliding, and calving.*
- ▶ *Greenhouse warming could lead to increased precipitation in Antarctica because of two mechanisms: (1) reduction of the surrounding sea ice allowing increased water vapor exchange and transport to the continent, and (2) increased water vapor content of the air due to increased temperature. [It has been estimated that] a precipitation increase of 12 to 30% based on a temperature increase of 3% to 8°C, over a 100-year period, would produce a sea-level fall of 0.08 to 0.20m.*

In the study, Meier takes on the issue of land ice's role in sea level change, and discusses whether large ice masses are actually melting and contributing to such changes. He notes at the beginning of his study that "the amount of ice on land at the present moment is huge, probably exceeding the sum of all other amounts of water substance in and on land. A continuing annual loss of only 0.001 to 0.002% of the land ice volume would be sufficient to cause the observed change of 1 to 2 mm/yr in global sea level." Meier adds, however, that much more observational data are needed before definitive conclusions on ice melt can be reached, and current results "will have to be considered tentative."

The Scientific Assessment of Climate Change

The Intergovernmental Panel on Climate Change, August 1990

Key Points

- ▶ ***Validation of Climate Models:*** "The latest [general circulation models (GCMs)], while by no means perfect, are thus sufficiently close to reality to inspire some confidence in their ability to predict the broad features of a doubled CO₂ climate at equilibrium, provided the changes in sea-surface temperature and sea-ice are correct...the validation of a number of atmospheric model variables has been handicapped by limitations in the available observed and model data."
- ▶ ***Equilibrium Climate Change:*** One of the largest sources of uncertainty in the simulation of equilibrium climate change lies in the prediction of clouds. It has been shown that clouds can produce either a positive or negative feedback, depending on the model and parameterization of cloud used....
- ▶ ***Observed Climate Variations and Change:*** We conclude that despite great limitations in the quantity and quality of the available historical temperature data, the evidence points consistently to a real but irregular warming over the last century. Because we do not understand the reasons for these past warming events it is not yet possible to attribute a specific proportion of the recent, smaller, warming to an increase of greenhouse gases."
- ▶ ***Detection of the Greenhouse Effect in the Observations:*** "Global-mean temperature has increased by 0.3-0.6 degrees C over the past 100 years....it remains to be established that the observed warming (or part of it) can be attributed to the enhanced greenhouse effect."
- ▶ ***Sea Level Rise:*** "Despite numerous problems associated with estimates of globally-coherent, secular changes in sea level based on tide gauge records, we conclude that it is highly likely that sea level has been rising over the last 100 years....There is no firm evidence of accelerations in sea level rise during this century."

Purpose of Science Working Group

The "Scientific Assessment of Climate Change" was prepared by the Intergovernmental Panel on Climate Change's (IPCC) Working Group One (WG I-Science Working Group) and is considered the most influential work to date on the science of global climate change.

WG I's purpose, as set forth by the IPCC, was to provide a scientific assessment of:

- ▶ the factors which may affect climate change during the next century especially those which are due to human activity.
- ▶ the responses of the atmosphere-ocean-land-ice system.
- ▶ the past climate record and presently observed climate anomalies.

WG I endeavored to present "current knowledge regarding predictions of climate change over the next century, the timing of the changes together with an assessment of the uncertainties associated with these predictions."

The authors noted that though uncertainties are attached to every aspect of the climate change issue, policymakers still look to scientists for clear guidance. WG I stressed that although this report was an indication of their understanding in 1990, "basic conclusions concerning the reality of the enhanced greenhouse effect and its potential to alter global climate are unlikely to change significantly."

Key conclusions of WG I

Greenhouse Gases and Aerosols: "Since the industrial revolution the atmospheric concentrations of several greenhouse gases, i.e., CO₂, methane, CFCs, nitrous oxide, and tropospheric ozone, have been increasing, primarily due to human activities. Several of these greenhouse gases have long atmospheric lifetimes, decades to centuries, which means that their atmospheric concentrations respond slowly to changes in emissions rates."

Radiative Forcing of Climate: "The climate of the Earth is affected by changes in radiative forcing due to several sources (known as radiative forcing agents): these include the concentrations of radiatively active (greenhouse) gases, solar radiation, aerosols and albedo (reflective power of clouds)....Natural effects on the forcing as a result of solar variability and volcanic eruptions are particularly relevant on decadal timescales....It is important to consider how these additional forcings may modify the atmospheric radiative forcing from that expected from greenhouse gases on both decadal and longer timescales."

Processes and Modeling: "Many facets of the climate system are not well understood, and a significant number of the uncertainties in modelling atmospheric, cryospheric and oceanic interactions are directly due to the representation of knowledge of interactive climate feedback mechanisms. Such feedback mechanisms can either amplify or reduce the climate response resulting from a given change of climate forcing....Unfortunately, even though this is crucial for climate change prediction, only a few models linking all the main components of the climate system in a comprehensive way have been developed."

Validation of Climate Models: "The latest [general circulation models (GCMs)], while by no means perfect, are thus sufficiently close to reality to inspire some confidence in their ability to predict the broad features of a doubled CO₂ climate at equilibrium, provided the changes in sea-surface temperature and sea-ice are correct....There is a clear need for further improvement of the accuracy of climate models through both increased resolution and improved parameterization of small scale processes, especially their treatment of convection, clouds and surface effects in atmospheric GCMs....the validation of a number of atmospheric model variables has been handicapped by limitations in the available observed and model data."

Equilibrium Climate Change: "All models show substantial changes in climate when CO₂ concentrations are doubled, even though the changes vary from model to model on a sub-continental scale....One of the largest sources of uncertainty in the simulation of equilibrium climate change lies in the prediction of clouds. It has been shown that clouds can produce either a positive or negative feedback, depending on the model and parameterization of cloud used....Another large uncertainty lies in the representation of convection in large-scale models....the changes in ground wetness and surface temperature have been shown to be highly sensitive to the treatment of the land surface. In addition, the effects of vegetation and changes in vegetation are ignored in the models used."

Time-Dependent Greenhouse-Gas-Induced Climate Change: "The slowly changing response of climate to a gradual increase in greenhouse gas concentrations can only be modelled rigorously using a coupled ocean-atmosphere GCM with full ocean dynamics. This has now been done by a small number of researchers using coarse resolution models out to 100 years. Their results show that: The regional patterns of temperature and precipitation change generally resemble those of an equilibrium simulation for an atmospheric model, though uniformly reduced in magnitude....However, available computer power is still a serious limitation on model capability, and existing observational data are inadequate to resolve basic issues about the relative roles of various mixing processes, thus affecting the confidence level that can be applied to these simulations."

Observed Climate Variations and Change: "The instrumental record of surface temperatures over the land and oceans remains sparse until after the middle of the nineteenth century....The record suggests a global (combined land and ocean) average warming of 0.45+-0.15 degrees Since the late nineteenth century, with an estimated small exaggeration due to urbanization in the land component. The greater part of the global temperature increase was measured prior to the mid-1940s....Reliable records of sea-ice and snow are too short to discern long-term changes....There is no evidence yet of global scale changes in the frequency of extreme temperatures....Uncertainties in these records are mostly too large to allow firm conclusions to be drawn....We conclude that despite great limitations in the quantity and quality of the available historical temperature data, the evidence points consistently to a real but irregular warming over the last century. A global warming of larger size has almost certainly occurred at least once since the end of the last glaciation without any appreciable

increase in greenhouse gases. Because we do not understand the reasons for these past warming events it is not yet possible to attribute a specific proportion of the recent, smaller, warming to an increase of greenhouse gases."

Detection of the Greenhouse Effect in the Observations: "Global-mean temperature has increased by 0.3-0.6 degrees C over the past 100 years....it remains to be established that the observed warming (or part of it) can be attributed to the enhanced greenhouse effect....Natural variability of the climate system could be as large as the changes observed to date, but there are insufficient data to be able to estimate its magnitude or its sign....Currently, there is only limited agreement between model predictions and observations. Reasons for this include the fact that climate models are still in an early stage of development, our inadequate knowledge of natural variability and other possible anthropogenic effects on climate, and the scarcity of suitable observational data, particularly long, reliable time series."

Sea Level Rise: "Despite numerous problems associated with estimates of globally-coherent, secular changes in sea level based on tide gauge records, we conclude that it is highly likely that sea level has been rising over the last 100 years....There is no firm evidence of accelerations in sea level rise during this century....From present data it is impossible to judge whether the Antarctic ice sheet as a whole is currently out of balance and is contributing, either positively or negatively, to changes in sea level....Even with the substantial decreases in the emissions of the major greenhouse gases, future increases in temperature and, consequently, sea level are unavoidable-a sea-level rise 'commitment'-due to lags in the climate system."

Effects on Ecosystems: "Because species respond differently to climatic change, some will increase in abundance while others will decrease. Ecosystems will therefore change in structure....Increased atmospheric CO₂ has the potential to increase plant growth in a variety of ways, including the depression of respiration and the relief of water and low light stresses....If elevated CO₂ does simulate the growth of woody vegetation, this could lead to long-term net carbon storage in terrestrial ecosystems."

Remaining Uncertainties

WG I stresses that in order to narrow the many uncertainties associated with the climate change issue, several key areas must be addressed. These areas include:

- ▶ control of the greenhouse gases by the Earth system;
- ▶ control of radiation by clouds;
- ▶ precipitation and evaporation;

- ▶ ocean transport and storage of heat; and
- ▶ ecosystem processes.

WG I suggests that all nations "reaffirm their commitment to observe and document the fundamental aspects of the climate system and the changes occurring within it, including:

- ▶ improvement of the global atmosphere and land surfaces observing system;
- ▶ development of a global ocean and ice observing system;
- ▶ establishment of a comprehensive system for climate monitoring."

Policy Implications of Greenhouse Warming—Report of the Synthesis Panel

National Academy of Sciences, April 1991.

Key Points

- ▶ ***Atmospheric CO₂ Concentration:*** *"Until the redistribution of newly emitted CO₂ is more thoroughly understood, reliable projections of the rate of increase of atmospheric CO₂ will lack credibility even for precisely estimated emission rates."*
- ▶ ***Climate Models:*** *"One major drawback common to all current GCMs is that they lack adequately validated representations of important factors like cloud cover feedback, ocean circulation, and hydrologic interactions. Therefore it is unreasonable to expect the models to provide precise predictions, decades into the future, of global average temperature."*
- ▶ *"Neither the available climate record nor the limited capabilities of the climate models permit a reliable forecast of the implications of continued accumulations of greenhouse gases in the atmosphere. However, it is probable that some positive rate of warming will accompany continued accumulation of greenhouse gases in the atmosphere. An important question is: When will we have a more definite fix on the rate at which warming will occur?"*

"It is unlikely that our understanding of such basic phenomena as the role of clouds and ocean dynamics will improve greatly over the next few years. It is also unlikely that a useful level of improvement in regional predictive capability will emerge in that time. A few decades may be required before atmospheric scientists produce the answers we seek."

This report was written by the Policy Implications of Greenhouse Warming Synthesis Panel, and assembled by the Committee on Science, Engineering, and Public Policy, a joint committee of the National Academy of Sciences (NAS), National Academy of Engineering (NAE), and the Institute of Medicine.

Chapter 3 ("Greenhouse Gases and Their Effects") focuses on the science of climate change. Key conclusions from Chapter 3 follow:

Overview

- ▶ **Atmospheric CO₂ Concentration:** "Recent measurements indicate that about 40 percent of the CO₂ released into the atmosphere stays there for decades at least, and about 15 percent seems to be incorporated into the upper layers of the oceans. The location of

the remaining 45 percent of the CO₂ from human activity is not known. Until the redistribution of newly emitted CO₂ is more thoroughly understood, reliable projections of the rate of increase of atmospheric CO₂ will lack credibility even for precisely estimated emission rates."

- ▶ Radiative Effects: "...each molecule of methane absorbs radiative energy 25 times more effectively than each molecule of CO₂, and CFC-12 is 15,800 times more effective than CO₂ on a per molecule basis and, since molecules of the two gases have different mass, 5,750 times more effective on a per mass basis."

What We Can Learn From Climate Models

- ▶ "The importance of greenhouse warming will be determined by the magnitude and abruptness of the associated climatic changes. Useful prediction requires credible quantitative estimates of those changes. Numerical computer simulations using general circulation models (GCMs) are generally considered the best available tools for anticipating climatic changes.

"One major drawback common to all current GCMs is that they lack adequately validated representations of important factors like cloud cover feedback, ocean circulation, and hydrologic interactions. Therefore it is unreasonable to expect the models to provide precise predictions, decades into the future, of global average temperature. This is especially so given that the expected global temperature rise is smaller than current naturally occurring regional temperature fluctuations on all time scales; daily, seasonal, and decadal."

"For the purposes of informed policy choice, it is crucial to acknowledge the limited capability of the GCMs. This is especially true because there is no clear connection between temperature records of the last century and the atmospheric accumulation of greenhouse gases."

"Although GCMs cannot produce scientific 'proof' in their predictions, they do map seasonal cycles of surface temperature quite well. GCMs also reasonably simulate daily and annual variations and annual variability in air pressure patterns over large areas."

What We Can Learn From the Temperature Record

- ▶ "The most comprehensive assessment of the record of surface temperature reveals a warming since the late nineteenth century of between 0.3 degrees and 0.6 degrees C. This warming is supported by several different kinds of information.

To some extent the natural temperature variation in the climatic system makes it difficult to interpret the observational record. In particular, it is not possible to determine how much, if any, of the average global temperature rise over the last century might be attributed to greenhouse warming.

Recent analyses raise the possibility that some greenhouse warming could be offset by the cooling effect of sulfate aerosol emissions. Such emissions may have contributed to regional temperature variations and to differences in the temperature records of the northern and southern hemispheres."

Sea Level

- ▶ "All of human civilization has lived in a period when the average sea level was roughly as it is today....Climate-related contributions to sea level change are of two kinds: variations in the actual amount or mass of water in the ocean basins and (due mostly to changes in precipitation and runoff) and thermal expansion or contraction (changes in the density of water, due to variations of temperature and salinity.

Some have suggested that global warming due to increased atmospheric concentrations of greenhouse gases could lead to disintegration of the West Antarctic Ice Sheet, most of which is grounded below sea level. If climate warms and warmer ocean water intrudes under the ice sheet, the release of ice from the sheet would accelerate. The melting of the West Antarctic Ice Sheet is quite unlikely, however, and virtually impossible by the end of the next century.

Thermal expansion (and contraction) of the oceans, caused by a combination of increasing (decreasing) temperature and salinity, accounts for seasonal and interannual variations in sea level. These changes are not large enough, however, to account for the differences over tens of thousands of years."

Conclusions

- ▶ "Neither the available climate record nor the limited capabilities of the climate models permit a reliable forecast of the implications of continued accumulations of greenhouse gases in the atmosphere. Neither do they permit an assessment as to whether the increase from 1890 to 1990 in global average temperature can be attributed to greenhouse gases. However, it is probable that some positive rate of warming will accompany continued accumulation of greenhouse gases in the atmosphere. An important question is: When will we have a more definite fix on the rate at which warming will occur?"

"It is unlikely that our understanding of such basic phenomena as the role of clouds and ocean dynamics will improve greatly over the next few years. It is also unlikely

that a useful level of improvement in regional predictive capability will emerge in that time. A few decades may be required before atmospheric scientists produce the answers we seek."

Sherwood Idso's Testimony

Before the California Energy Resources Conservation and Development Commission (CERCDC), November 19, 1991.

Key Points

- ▶ *"Contrary to what one might first expect, when water or nutrients are limiting, the relative growth enhancement [of plants] due to CO₂ enrichment is generally even greater, as it also is at higher temperatures."*
- ▶ *"With respect to earth's forests, the positive effects of atmospheric CO₂ enrichment are even more impressive. In an on-going, long-term study of sour orange trees in Phoenix, Arizona, for example, a 300 ppm increase in the CO₂ content of the air has produced a 2.8-fold increase in both above - and below-ground biomass. And it has recently been demonstrated that, in the mean, all of earth's trees respond similarly."*
- ▶ *"It is abundantly clear that increases in primary production arising from atmospheric CO₂ enrichment set in motion a cascade of biological activity that further increases vegetative productivity and enhances the vigor of earth's entire web of life."*
- ▶ *"...nearly every biological process that is stimulated by enhanced vegetative productivity resulting from atmospheric CO₂ enrichment has an additional growth-promoting effect that enhances vegetative productivity even more..."*
- ▶ *"...there is as yet no solid evidence that CO₂'s single perceived negative impact, i.e., enhanced CO₂-induced global warming, really exists. Indeed, nearly everyone who has studied the subject is careful to admit that its basic tenet is still unproven. And most of them recognize that it will take a decade or more of data acquisition and analysis to even have the potential to adequately test the hypothesis."*

In his testimony before the CERCDC, Idso noted that one of the major effects of atmospheric CO₂ enrichment on plants was "an increase in growth...Practically everything that plants do...they do better with more CO₂." Idso maintained that there were two basic reasons for this phenomenon:

- 1) "CO₂ is the primary raw material used by plants to produce food via the process of photosynthesis.
- 2) Throughout geologic time, there was always more CO₂ in the air than there is today. For this reason, plants are simply better adapted to high CO₂ concentrations."

Global Warming: Evidence For Asymmetric Diurnal Temperature Change

By Thomas R. Karl, National Oceanic and Atmospheric Administration, December 1991.

Key points

- ▶ *"The causes of the asymmetric diurnal changes are uncertain, but there is some evidence to suggest that changes in cloud cover play a direct role (where increases in cloudiness result in reduced maximum and higher minimum temperatures)."*
- ▶ *"Regardless of the exact causes, [results of the study] imply that either: (1) climate model projections considering the expected change in the diurnal temperature range with increased levels of the greenhouse gases are underestimating (overestimating) the rise of the daily minimum, or (2) the observed warming in a considerable portion of the Northern Hemisphere landmass is significantly affected by factors unrelated to an enhanced anthropogenically-induced greenhouse effect."*
- ▶ *..."it is entirely possible that the observed changes are the result of natural fluctuations within the climate system."*
- ▶ *"At present we lack an adequate understanding of the causes of differential changes in the mean and extremes of maximum and minimum temperatures. This is a fundamental characteristic of recent climate variation over a large portion of the northern hemisphere land mass, and it must be better understood before we can confidently project the climate or climate impacts on future society and ecosystems."*

This study is an update of Karl's year-month mean maximum and minimum surface thermometric record. The update was expanded to cover three large countries (United States, USSR, and China). Karl concludes that "most of the warming which has occurred in [the above-mentioned regions] over the past four decades can be attributed to an increase of mean minimum (mostly nighttime) temperatures. Mean maximum (mostly daytime) temperatures display little or no warming."

Patrick Michaels Testimony

Before the California Energy Commission, 1991.

Key Points

- ▶ *Current generation General Circulation Models (GCMs) "have overestimated warming by a factor of between two and four. The scenarios of great cost to society are predicated upon the opposite of what has occurred."*
- ▶ *"The use of knowingly incorrect parameters, and the inversion of the entire globe—in which the Northern Hemisphere that should warm up does not, while the opposite occurs in the Southern Hemisphere—should easily be enough to discredit GCMs as vehicles for policy."*
- ▶ *"Global Warming is taking place at a rate far below that required to support a 4.0 degrees Celsius warming by the mid-21st century."*
- ▶ *"The Southern Hemisphere shows more warming than the Northern Hemisphere during the last 40 years, which is opposite to GCM calculations that are being used as the basis for policy."*

Patrick Michaels, Associate Professor of Environmental Sciences at the University of Virginia, is a leading critic of the "popular vision" that a catastrophic climate change is at hand. Michaels has delivered over 50 invited lectures on climatic change, and has testified twice before the House of Representatives, and twice before the Senate. He maintains that the current generation of General Circulation Models (GCMs) "are inappropriate for estimation of climatic change over areas of significant impact" and that such models "...are based upon physical parameters, that are known to be incorrect, in order to achieve a desired result."

Key points from Michaels' testimony:

GCMs

- ▶ Current generation GCMs "have overestimated warming by a factor of between two and four. Further, the observed character of climate change in the face of the greenhouse enhancement has been to primarily warm winter nights, and to cool summer days. The scenarios of great cost to society are predicated upon the opposite of what has occurred."

- ▶ "The consensus that the models are drastically flawed permeates the relevant scientific community...Imagine an analogous situation, in which a weather forecasting model started off with bad data that said summer temperatures in the corn and soybean belt were ten degrees higher than they actually are. The subsequent forecast high temperatures for the next day would likely be very warm, but the error could be masked if one neatly subtracted the difference between the forecast temperature and the erroneously input initial conditions. This is what occurs in the climate models."
- ▶ "Given all of these observations it is indefensible to use GCMs as a basis for any expensive energy policies. The use of knowingly incorrect parameters, and the inversion of the entire globe—in which the Northern Hemisphere that should warm up does not, while the opposite occurs in the Southern Hemisphere—should easily be enough to discredit GCMs as vehicles for policy."

Temperature History

- ▶ "Taking the earth's temperature from ground-based thermometers is a daunting proposition, owing to the fact that cities tend to grow up around (and artificially warm) their weather stations, and because the site selection for those very stations is climatically nonrandom...One land-based record has scrupulously attempted to remove these biases. It is known as the "Historical Climate Record" (HCN)...The HCN shows no warming in the 20th century. It is...the most reliable of our land-based records when judged by how well it matches the satellite-sensed record that begins in 1979."

Cloud Cover

- ▶ "The ecological implications of a greenhouse warming modulated by an increase in low-level clouds are profound. The apocalyptic vision of withered crops, burning forests compromised by poor growth because the climate has changed so fast that the trees can't follow, and sea level rise inundating the world's major ports and cultural centers, is driven by daytime warming and the melting of vast areas of land ice.

"Low level clouds are so bright that they provide a net cooling, even as they warm the nights. Thus daytime temperatures would cool if only the clouds dominated, while the effect might be neutral during the day if the greenhouse enhancement was sufficient to counter the cloud effect."

Sea Level Rise

- ▶ "The prospect of disastrous sea level rise caused by melting land ice meets a similar end with night, rather than day, warming. The high-latitude regions with continental ice sheets tend to be very cold—minus 40 degrees or so—during the long polar night. Thus any foreseeable night warming does not bring the temperature up to freezing. If

cloud days prevent much summer warming, it will therefore be very difficult to melt much ice."

Snowcover

- ▶ "A recent report in Nature magazine that the north polar ice margin has shrunk by two percent since 1979 is often cited as evidence for a disastrous warming. This followed a National Oceanic and Atmospheric Administration (NOAA) report that appeared about a year earlier, demonstrating that North American maximum snowcover was at its lowest value, again since 1979."

"These observations are made from satellites, and some of the orbiters were in place long before 1979. In 1980, Don Wiesnet and Michael Matson, also of NOAA, published an article describing satellite snowcover measurements since record began in 1966. [They concluded that] northern hemisphere maximum snowcover rose by approximately 18% between 1966 and the late 1970s."

"In fact, 1978 marks the high point for snowcover in North America. Starting a record at a high point and then using subsequent trends as evidence for an enhanced greenhouse is inappropriate and should not be a basis for policy."

Conclusions

1. "The data do not support the models that are used to determine warming-related externalities. The models themselves are based upon knowingly incorrect parameters, including the amount of solar radiation reaching the earth."
2. "Global Warming is taking place at a rate far below that required to support a 4.0 degrees C warming by the mid-21st century."
3. "The Southern Hemisphere shows more warming than the Northern Hemisphere during the last 40 years, which is opposite to GCM calculations that are being used as the basis for policy."
4. "At least in the Northern Hemisphere, it appears that summer days are cooling and winter nights are warming. This combination is ecologically and agriculturally preferable to the current climate."
5. "Virtually all observations are consistent with an increase in cloudiness being fueled by industrial activity. Thus the same activity that produces enhanced greenhouse emissions has channeled them into a neutral or possibly beneficial expression."

POLICY DEVELOPMENT

WASHINGTON INTERNATIONAL ENERGY GROUP

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2. *Intergovernmental Panel on Climate Change (IPCC)—Response Strategies*, Working Group III, World Meteorological Organization and United Nations Environment Programme, 1991.
3. *Changing by Degrees: Steps to Reduce Greenhouse Gases*, Executive Summary and Main Report, Office of Technology Assessment, February 1991.
4. Singer, S. Fred, *Global Warming: Do We Know Enough to Act?* Center for the Study of American Business, Washington University, March 1991.
5. National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, *Policy Implications of Greenhouse Warming: Report of the Synthesis Panel, Report of the Mitigation Panel, and Report of the Adaptation Panel*, National Academy Press, Washington, D.C., 1991.

Chronology of Global Climate Change Policy

Overview

Over the last ten years the debate surrounding the potential effects of global warming has rapidly intensified. The increase in attention given to the issue, on the part of policymakers in and outside the United States, reflects the mounting political pressure to take action and a greater public awareness and concern over the issue.

Although the volume of information about global climate change has grown tremendously, the uncertainty regarding the timing and magnitude of the potential threat remains high. While scientists are charged with discovering the facts, policymakers are faced with the difficult task of determining how and when, if ever, to respond to the potential threat.

A chronological review of domestic global climate change policy related activities illustrates not only the release dates of major policy reports, but those events in which the United States has participated over the last decade.

(Note: A * indicates that the particular report is summarized in greater detail in the **Policy Summaries** section of this report.)

1983

The U.S. Environmental Protection Agency (EPA) report, *Can We Delay A Greenhouse Warming* is released. The report warns that greenhouse gases in the atmosphere are sufficient to cause a global temperature rise of about 3.6° Fahrenheit (F) or 2° Centigrade (C).

A National Academy of Sciences (NAS) report, *Changing Climate*, argues that there is not enough evidence to support a shift away from fossil fuel use.

1985

V. Ramanathan and Ralph J. Cicerone of the National Center for Atmospheric Research (NCAR) claim that other greenhouse gases together cause global warming to the same degree as CO₂. They propose that warming could actually take place rapidly.

NAS report, *Glaciers, Ice Sheets, and Sea Level: Effects of a CO₂-induced Climatic Change* is released.

October—International Conference on the Assessment of the Role of Carbon Dioxide and Other Greenhouse Gases in Climate Variations and Associated Impacts (Austria) is sponsored by World Climate Program of United Nations Environment Programme (UNEP), the World Meteorological Organization (WMO), and the International Council of Scientific Unions (ICSU). Some participants suggest that some warming is inevitable, but governmental conservation, emissions, and fuel use policies could have considerable influence on managing the warming. They recommend that governments consider greenhouse effects in policy-making, and that decision-makers and scientists work together closely.

1986

U.S. EPA and UNEP jointly publish major report, *Effects of Changes in Stratospheric Ozone and Global Climate*. The report states that global atmospheric changes are already occurring.

1987

The "Brundtland Commission" or World Commission on Environment and Development report, *Our Common Future*, points out that relying on fossil fuels for energy will be a problem in light of global warming risks.

NAS report, *Responding to Changes in Sea Level: Engineering Implications* is released.

September—The "Montreal Protocol on Substances that Deplete the Ozone Layer" is adopted by 24 nations.

September/November—Joint UNEP/WMO meetings in Villach, Austria and Bellagio, Italy. The predominant theme is the idea that global warming will occur faster in the future, but governments can influence the rate of change. Participants agree that it is reasonable to believe that some natural systems will not survive under the expected rate of change.

1988

The U.S. Global Climate Protection Act is enacted. The Act requires the Administration to expand research on preventive measures and a plan for stabilizing greenhouse gases in the atmosphere.

A very hot summer raises media interest and public concern about the global warming phenomena.

Senator Timothy Wirth (D-CO) chairs a hearing to discuss the findings from the Villach and Bellagio meetings and the heat wave. J. Hansen of the Goddard Institute for Space Studies testifies that temperature rise is not just due to natural phenomena, but is related to CO₂ emissions from anthropogenic sources.

The Toronto World Conference on the Changing Atmosphere: Implications for Global Security is held. The participants collectively acknowledge that changes in the atmosphere are real, and that there is a need to take action by cutting CO₂ emissions by 20 percent by 2005.

November—The first Intergovernmental Panel on Climate Change (IPCC) meeting is held in Geneva. IPCC becomes the major international forum for scientific views on global climate change.

December—UN General Assembly resolution is passed, calling for a framework convention on climate change.

*The Committee on Science, Engineering and Public Policy, under the auspices of the National Academy of Sciences (NAS), National Academy of Engineers and the Institute Of Medicine is commissioned by Congress to complete a comprehensive study, *Policy Implications of Greenhouse Warming*.¹ The study is partitioned into four parts, the Synthesis Panel, Adaptation Panel, Mitigation Panel and the Effects Panel. The Panels conduct independent, parallel research to "establish the scientific consensus on the rate and magnitude of climate change, estimate the projected impacts, and evaluated policy options for mitigating

¹ The Congressional directive for the comprehensive study is the HUD-Independent Agencies Appropriations Act of 1988, House Report 100-701:26.

and responding to such changes." The collective studies will be placed in one volume due for publication in 1992.

1989

Scientific Perspectives on the Greenhouse Problem is published by the George C. Marshall Institute. The report suggests that sunspots and other natural phenomena may be the major determinant for weather, although there is not enough scientific understanding to act. More research is needed before any response strategy can be developed.

The "Hague Declaration" calls for an international institution with enforcement authority to uphold an international global warming agreement.

Seven Organization of Economic Cooperation and Development (OECD) countries hold the "Green Summit" in Paris. The group passes 19 resolutions concerning the environment. The resolutions call for environmental protection policies despite the lack of certainty in some cases, and support the need to assess costs, benefits and resource impacts of policies. The common goal stated is to limit CO₂ and other greenhouse gases emissions, although no specific commitment is made. The members also call for a framework convention.

September—A World Conference in Tokyo on Global Environmental Conservation Towards Sustainable Development is held. The consensus supported is that global climate change is an international "environmental challenge requiring commitment to "environmental ethics."

November—"Noordwijk" Ministerial Conference on Atmospheric Pollution and Climate Change (Netherlands). Specific targets and timetables are rejected by the U.S., Japan, and the Soviet Union. The IPCC and Second World Climate Conference are designated for consideration of appropriate levels.

December—The "Cairo Compact" concludes the World Conference on Preparing for Climate Change (sponsored by Climate Institute, UNEP, and Egypt). The Compact calls for a internationally planned response to the global climate "crisis".

1990

The first carbon-content taxes on fossil fuel use are set by the Netherlands, Finland and Norway.

NAS report, *Sea Level Change* is released.

February—IPCC holds its Third General Session. President Bush advocates support for continued research, and calls upon members to adhere to a cautious policy-making approach.

April—The U.S. sponsors the White House Conference on Science and Economic Research Related to Global Change. President Bush stresses that scientific uncertainties and economic questions still surround the climate change debate. The U.S. says that stabilization of total greenhouse gas emissions is possible by the year 2000. Other delegates criticize the U.S. lack of commitment, and call for immediate and comprehensive action to reduce greenhouse gas emissions. Some countries take unilateral measures, for instance, Germany, Netherlands, France, Denmark, Finland, and Norway.

April—The Ministry of International Trade and Industry (MITI, Japan) proposes the "New Earth 21" Program for Action on Climate Change. MITI commits \$2.8 billion for research and development on global environmental problems. The goal stated is to turn back the greenhouse gas emissions effect over last 200 years during next 100 years.

April—The Interparliamentary Conference on the Global Environment is held in Washington, D.C.. Delegates agree to a goal of reducing global greenhouse gas (CO₂, methane, CFCs) emissions by 50 percent by 2010.

May—UN Economic Commission for Europe (ECE) conference is held in Norway. The theme is an "Action for a Common Future." A "Precautionary Principle," in the final declaration, advises taking preventive measures, despite lack of scientific evidence, and requires participating countries to develop CO₂ strategies by February 1991.

May—Canada announces its plan to stabilize CO₂ emissions at 1990 levels by 2000.

June—The German Cabinet approves a goal of reducing CO₂ emissions by 25 percent from 1987 levels by 2005.²

August—A United Nations/IPCC conference in Sundsvall, Sweden adopts reports on scientific findings and consequences of Global Warming, but fails to set common formula for future action.

August—The report, *Carbon Charges as a Response to Global Warming: the Effects of Taxing Fossil Fuels*, is released by CBO.

October—German Parliament's Special Committee on Environment adopts a resolution calling for a 30 percent reduction of CO₂ by 2005.

October—The final resolution at the Second World Climate Conference (Geneva) contains a compromise between the United States and Western Europe. It does not, however, establish a

² Final adoption in January 1991 set target reductions of 25-30 percent.

specific CO₂ reduction target despite the unified support of the EC and the EFTA (European Free Trade Association) for stabilizing CO₂ emissions at 1990 levels by 2000.

*December—The Environmental Protection Agency, Office of Policy, Planning and Evaluation releases its report, *Policy Options For Stabilizing Global Climate*. It states that regardless of how the earth's climate will change and what the exact effects will be, taking steps to reduce emissions now is sure to affect the speed and magnitude of some of those changes.

1991

**Intergovernmental Panel on Climate Change (IPCC)—Response Strategies* is released. The report is the work of Working Group III, one part of the World Meteorological Organization and United Nations Environment Program's Framework Convention on Climate Change.

January—President Bush asks Congress for \$1.18 billion (a 24 percent increase from FY 1991) to fund global climate change research in Fiscal Year 1992.

January—The German government adopts a non-binding agreement to reduce CO₂ emissions by 25-30 percent by 2005.

February—The first session of the Intergovernmental Negotiating Committee (INC) for a Framework Convention on Climate Change is held in Chantilly, Virginia. Two working groups; one on commitments, and one on mechanisms are established.

February—At the first Framework Convention session, the U.S. reaffirms its ability to stabilize its overall greenhouse gas emissions at 1987 levels by 2000, but continues to oppose CO₂ targets and timetables.

*February—The Office of Technology Assessment (OTA) releases a report entitled, *Changing by Degrees: Steps to Reduce Greenhouse Gases*. The report notes that rapidly increasing energy production and use are two major factors contributing to the increasing environmental pollution in the developing world.

February—The CBO releases, *Energy Use and Emissions of Carbon Dioxide: Federal Spending and Credit Programs and Tax Policies* report. The study points out that "[t]he net effect of current federal programs and policies on the consumption of fossil fuels is likely to be small...."

*March—S. Fred Singer, author of *Global Warming: Do We Know Enough to Act?* claims in his study that, "the scientific base for an enhanced greenhouse warming due to human activities is too uncertain to justify drastic action at this time."

*April—*Policy Implications of Greenhouse Warming-Report of the Synthesis Panel* is released. It recommends the adoption of major energy conservation measures through national building codes, energy pricing that factors in environmental costs under the "polluter pays" principle, and the reduction of global deforestation with international programs to assess the extent of deforestation, especially in tropical areas.

April—The Data Resources Institute (DRI)/McGraw-Hill publishes a report for the Department of Commerce (DOC) titled *The Economic Effects of Restrictions on Coal and Petroleum Fuels in Stationary Uses* which concludes that the institution of a multilateral strategy to restrict the use of coal in OECD countries, by employing a market permits system, would have negative economic effects on any OECD country.

April—U.S. EPA Administrator William Reilly announces that ozone loss in the upper atmosphere is proceeding twice as fast as originally predicted.

April—An OECD report, *Greenhouse Gas Emissions: The Energy Dimension*, concludes that "energy efficiency and fuel substitution represent the best areas for near-term responses to limit energy-related greenhouse gas emissions..."

April—The second World Industry Conference on Environmental Management (WICEM II) in Rotterdam concludes with participants agreeing that, "Although subject to uncertainty and scientific debate, the consequences of global warming are such that nations must identify those steps which can be taken now [to fight climate change]."

May—Two California utilities, Southern California Edison (SCE) and the Los Angeles Department of Water and Power (LADWP), pledge to reduce their CO₂ emissions by 10 percent from 1988-89 levels and another 10 percent by 2010.

*May—A final draft of the U.S. EPA report, *Policy Options for Stabilizing Global Climate* warns that a warming of 2-4° C is possible if greenhouse gas abatement programs are not instituted now.

June—Japanese and UK delegations at the second INC Framework Convention meeting in Geneva propose a "pledge and review" approach to global warming policy-making. Bush Administration officials informally support the "pledge and review" concept at the session. "Pledge and review" is based on the premise that countries will develop their own plan on how to deal with greenhouse gas emissions, while subjecting themselves to periodic "progress" reviews by other countries.

*June—*Policy Implications of Greenhouse Warming-Report of the Mitigation Panel* is released. It classifies various methods of reducing greenhouse gases by cost, impacts, feasibility and relative cost-effectiveness.

September—Third INC Framework Convention meets in Nairobi.

*September—*Policy Implications of Greenhouse Warming-Report of the Adaptation Panel* is released. The study concludes that, in the developed world, the effects of climate change on human health and economic productivity would be minimal, except for the fishing and farming sectors—which contribute less than 3 percent of the Gross National Product (GNP) in the U.S.. The report notes, however, that adaptation will be more problematic for developing countries.

October—In a report entitled, *Scientific Assessment of Stratospheric Ozone: 1991*, a panel of UN scientists finds, for the first time, that depletion of the ozone layer 15 to 20 miles above the earth occurred in the spring and summer months in both the northern and southern hemispheres.

October—A Data Resources, Inc./McGraw-Hill report, *Carbon Dioxide Emissions and Federal Energy Policy: A Discussion of the Economic Consequences of Alternative Taxes*, contends that taxes would be effective in reducing CO₂ emissions, but not without adverse effects on the economy. The report stresses that tradeoffs must be made between CO₂ reduction, economic growth and other environmental issues, and recommends that the best CO₂ control policy is one that reduces emissions with the least possible effect on the economy.

December—INC Framework Convention session in Geneva.

1992

January—the Fiscal Year 93 budget request for global climate change research and development is \$1.37 billion, a 24 percent increase over the 1992 budget approved by Congress.

February—A team of NASA scientists discovers higher than expected levels of ozone depleting chemicals over New England and eastern Canada.

February—President Bush announces that the U.S. will ban the manufacturing of ozone depleting chemicals by December 31, 1995, five years earlier than the Montreal Protocol requires.

February—INC Framework Convention meeting in New York City.

April—INC Framework Convention meetings.

June—UN Conference on Environment and Development (UNCED) "Earth Summit", Rio de Janeiro, Brazil.

Policy Options for Stabilizing Global Climate Change

Main Report to Congress, Office of Policy, Planning & Evaluation, U.S. Environmental Protection Agency, December 1990. (Lashof, Daniel A. and Dennis A. Tirpak)

Key Points

Policy Options for Stabilizing Global Climate Change, a report, produced at the request of Congress, identifies policy options that have the potential to stabilize current levels of atmospheric greenhouse gas concentrations. The report stipulates that avoiding policy-making on the grounds of uncertainty is not wise considering that a variety of options exists. Six scenarios incorporating different levels of economic development, population growth, and technical development were considered under three policy conditions; no policy, stabilization policy and rapid emissions reduction policy. The main policy recommendations include: (1) encourage energy efficiency; (2) increase in the use of non-fossil energy sources; (3) reduce emissions from current fossil-fuel generation, and; (4) reduce emissions from non-energy sources. The policy advocated involves short-term efficiency efforts with existing technologies, combined with a longer-term commitment to advanced, non-fossil energy technologies. It also recognizes that advances in end-use technologies will also contribute to reducing energy requirements.

The study acknowledges that the current level of scientific uncertainty surrounding the greenhouse gas debate is significant; however, because the scientific community is becoming increasingly concerned about the issue, there is reason enough to act. As the EPA report notes, regardless of how the earth's climate will change and what the exact effects will be, taking steps to reduce emissions now is sure to affect the speed and magnitude of some of those changes.

The report states, "The most direct means of allowing markets to incorporate the risk of climate change is to ensure that the prices of fossil fuels and other sources of greenhouse gases reflect their full social cost. The report advocates federal and state regulatory efforts to compliment pricing strategies as well as voluntary private efforts to combat growth in greenhouse gas emissions.

Efficiency Options

- ▶ Improve energy end-use technologies.
- ▶ Improve the efficiency of the transportation sector.

- ▶ Implement greater residential and commercial sector efficiency standards.³
- ▶ Fuel switch from coal to natural gas.
- ▶ Use alternative fuels, and expand the use of hydroelectric, solar, wind, biomass, and geothermal power.

Emissions Controls Options

- ▶ Reduce carbon monoxide and nitrous oxide with existing technologies.
- ▶ Reduce emissions from coal seams, natural gas production and landfills.
- ▶ Encourage reforestation and management of existing forests to both increase forest biomass and lower the demand for wood in scarce resource areas.
- ▶ Eliminate CFCs and other related compounds.
- ▶ Control emissions from agricultural sources such as rice production, livestock, biomass burning and fertilizer use.

Overall, the report suggests that further research and development of advanced technologies is the crucial piece of all global climate change policy-making. There are current technologies that have the capability to reduce emissions as more advanced systems are studied and management strategies for their deployment are devised.

The timing of policy implementation is debatable, but "the models indicate that delaying the policy response to the greenhouse gas buildup would substantially increase the global commitment to future warming." It was also noted that some of policies underway to address other environmental concerns simultaneously help reduce greenhouse gas emissions, hence making a contribution to the overall effort.

The need for an international response strategy was stressed, as was the importance of the involvement of developing countries, because without their participation, the risk of global climate change will not be reduced.

³ By improving lighting, space conditioning and appliance efficiency energy consumption per square foot could be reduced by 75 percent in the residential and 50 percent in the commercial sectors.

Intergovernmental Panel on Climate Change—Response Strategies

Working Group III, World Meteorological Organization and United Nations Environment Programme, 1991.

The IPCC Response Strategies report consists of the policy options outlined by the IPCC Working Group III, in context of the findings of Working Group I (Science) and Working Group II (Impacts).

Key Points

- ▶ *"Emissions from human activities are significantly increasing the atmospheric concentration of greenhouse gases, which will enhance the greenhouse effect, leading to an overall warming of the Earth's surface."*
- ▶ *"Immediate emissions reductions of 60 percent would be required to stabilize long-lived gases at their present-day levels."*
- ▶ *"Ecosystems will be effected by changes in climate; some species may benefit, while others may struggle to adapt or become extinct."*
- ▶ *"The impacts of global climate change will be hardest felt in the developing world, as many developing nations may lack the necessary tools of adaptation that are available to the developed world."*
- ▶ *"Because of the global nature of the issue, both developed and developing nations must accept responsibility, however, industrialized nations must acknowledge that the bulk of emissions has originated from their industrial practices, and international initiatives must not unfairly impede the progress of the developing world."*

Policy Recommendations—A Flexible and Progressive Approach

- ▶ Improve energy efficiency and conservation in energy supply, conversion and end-use.
- ▶ Use cleaner energy sources and newer advanced technologies (hydro, natural gas, solar, alternative fuels, geothermal, wind, etc.), and fuel switch to non or low emitting fuels.
- ▶ Improve technologies for capturing or recovering leaking gases from fossil fuel storage, coal mining and improve maintenance of oil and natural gas production and distribution systems.

- ▶ Improve forest management and expansion of forest areas where feasible.
- ▶ Improve agricultural land use management, livestock management, and alter the use and formulation of fertilizers.
- ▶ Develop emergency and disaster preparedness policies and programs.
- ▶ Develop comprehensive area and land-use management plans for areas and populations most vulnerable to changes in climate (coastal areas and sensitive ecosystems).
- ▶ Accelerate and coordinate research programs.
- ▶ Develop new technologies for the energy, industrial and agricultural sectors.
- ▶ Review the planning, resource use and management of energy, industrial, agricultural, urban and coastal areas.
- ▶ Encourage behavior and structural changes (transportation and housing infrastructure).
- ▶ Expand global ocean observing and monitoring systems.

Working Group III did **not** assess the economic costs, technological feasibility, or the market potential for these policy recommendations, but formulated their strategies based on extensive research of the sources of greenhouse gases, the current and expected levels of **all** greenhouse gas emissions, the expected trends in economic development, population growth, energy supply, energy demand, deforestation, and agriculture, and the more specific attributes of different contributing sectors, (e.g. energy, transportation, buildings. industry).

Four Emissions Scenarios were considered: (1) 2030 High Emissions; (2) 2060 Low Emissions; (3) Control Policies; and (4) Accelerated Policies.

There were four Subgroup Reports: (1) Energy and Industry; (2) Agriculture, Forestry, and Other Human Activities; (3) Coastal Zone Management; and (4) Resource Use and Management.

Five types of implementation measures were addressed: (1) Public Education and Information; (2) Technology Development and Transfer; (3) Economic (Market) Measures; (4) Financial Mechanisms; and (5) Legal and Institutional Mechanisms.

Changing by Degrees: Steps to Reduce Greenhouse Gases

Office of Technology Assessment (OTA), February 1991.

Key Points

The report examined reduction potentials for CO₂ over the next 25 years, in the U.S. and elsewhere. The objective was: "Can the United States reduce carbon dioxide emissions in the near term?" The report notes, "This task is clearly more daunting since most industrialized nations currently depend so heavily on fossil fuels—the major source of carbon dioxide—for their economic well-being." Three different scenarios: Base case (business as usual), Moderate (essentially no-cost), and Tough were considered in six key sectors: Buildings, Transportation, Manufacturing, Energy Supply, Forestry, and Food. The policy options outlined by OTA involved three broad goals: (1) increasing energy conversion and efficiency in end-use technologies; (2) changing energy use patterns to increase conservation; and (3) shifting energy supply away from high CO₂ emitting fuels.

Although the report focused on the U.S., the global nature of the problem dictated that the needs of both the industrialized and developing world be taken into consideration.

It was determined that only the Tough case scenario would fulfill the specific Congressional request of a reduction of future CO₂ emissions by 25-30 percent from today's level in 2015. The economics and political reality of the situation make implementation of the Tough case scenario very unlikely, not to mention the limited timeframe.

Throughout OTA's assessment there is an underlying theme that larger research and development efforts are essential for the commercialization of new and advanced efficient technologies that will help mitigate, if not eliminate, further growth in overall greenhouse emissions.

The Baseline Scenario revealed that if the U.S. status quo is supported and growth projections are reasonably accurate, there will most likely be a 50 percent increase in CO₂ emissions over the next 25 years. OTA considers this scenario unacceptable.

The Moderate Scenario focal point is energy conservation. Compared to no policy, modest policies designed to encourage development, commercialization and use of new and efficient technologies would lead to a significantly lower increase in CO₂ emission levels, perhaps 15 percent.

The Tough Scenario would significantly lower energy demand, but at relatively high costs. Implementation of the Tough case scenario would lead to inconvenience as well as political, economical and social challenges.

Technical Options

- ▶ Fuel switch from coal to natural gas, and use non-fossil fuels altogether.
- ▶ Improve energy end-use.
- ▶ Commercialize more efficient advanced technologies.
- ▶ Encourage changes in energy use behavior.

Policy Instruments

- ▶ A general tax to stimulate greater energy efficiency, regardless of whether energy is derived from fossil or non-fossil fuels.
- ▶ Financial incentives, loans, subsidies, tax exemptions.
- ▶ Marketable permits.
- ▶ Regulations to remove high emitters from the market by setting standards.
- ▶ Research, development, and demonstration (RD&D).
- ▶ Information and public education.

OTA is convinced that, "climate change can only be effectively addressed over the long-term with the development and worldwide use of better non-fossil energy sources."

Global Warming: Do We Know Enough to Act

S. Fred Singer, March 1991

Singer claims, "The scientific base for an enhanced greenhouse warming due to human activities is too uncertain to justify drastic action at this time....There is little risk in delaying policy responses to this century-old problem since there is every expectation that scientific understanding will be substantially improved within a few years....Instead of panicky...and likely ineffective actions that would only slow down, but not stop, the further growth of CO₂, we may prefer to use the same resources—several trillion dollars by some estimates—to increase our economic resilience so that we can then apply specific remedies, if and as necessary."

Key Points

- ▶ Singer claims that the IPCC Policymakers summary ignores, "valid scientific objections to the theoretical calculations that predict a global warming. It is silent about other human activities, notably the emissions of sulfur dioxide in industrial processes, that are thought to promote a climate cooling."
- ▶ Many scientists call attention to the evidence supporting the fact that the strongest temperature increase occurred before 1938, when greenhouse gas concentrations were low, and preceding the 30% rise in carbon dioxide emissions that occurred since World War II.

Policy Recommendations

- ▶ Promote energy conservation through pricing. [Energy] prices should include the external costs that are avoided by the user and transferred to someone else. The idea is to have the polluter or the beneficiary pay the cost. For example, increase the tax on gasoline to make it a true highway user fee—instead of the current method of having most capital and maintenance costs paid by various state taxes.
- ▶ Improve Energy Efficiency.
 - provide consumers with more information about home heating costs, lighting, refrigeration, etc.,
 - encourage turnover and replacement of older, less efficient capital equipment such as cars, machinery and power plants

- stimulate private-sector development of more efficient systems, such as combined-cycle power plants or a more efficient internal combustion engine

- ▶ Encourage the use of non-fossil fuels.

Policy Implications of Greenhouse Warming—Synthesis Panel, Adaptation Panel and Mitigation Panel

Committee on Science, Engineering and Public Policy
National Academy of Sciences, National Academy of Engineering and Institute of Medicine,
1991

The report, Policy Implications of Greenhouse Warming, is a comprehensive study of global climate change, conducted under the auspices of the Committee on Science, Engineering and Public Policy, a unit of the councils of the National Academy of Sciences (NAS), National Academy of Engineering and Institute of Medicine.⁴ The study was commissioned by Congress in 1988, and subsequently divided into four parts; the Synthesis Panel, Adaptation Panel, Mitigation Panel and Effects Panel. Each panel conducts independent, parallel research, although interaction and sharing of information is common among the panels. The purpose of the collective study is to, "establish the scientific consensus on the rate and magnitude of climate change, estimate the projected impacts, and evaluate policy options for mitigating and responding to such changes." A collective volume of the findings of all four panels is to be released in March 1992.

⁴ The NAS is considered the federal government's top advisory body on scientific and technical matters.

Policy Implications of Greenhouse Warming—Report of the Synthesis Panel

Key Points

The Synthesis Panel was charged with organizing all four of the panels' findings and recommendations. The Synthesis Panel made recommendations based on the need for "insurance" against the potentially catastrophic effects of climate change.

The Synthesis Panel agreed with the Bush Administration on two accounts; that the current scientific evidence of global climate change effects is complex and to some extent inconclusive, and that global circulation models do not provide a reliable picture of future global warming scenarios. However, the Panel did endorse an immediate commitment to moderate policy initiatives as a more prudent course of action than postponing policy decisions until the science was more conclusive. The Panel found that moderate policy initiatives could lower U.S. greenhouse gas emissions by between 10 and 40 percent of 1990 levels at a very low cost.

Policy Recommendations

- ▶ Stiff energy conservation measures, including action to adopt nationwide energy-efficient building codes.
- ▶ Implementation of energy prices that factor in the environmental costs.
- ▶ Initiatives to reduce global deforestation.
- ▶ Continue the aggressive phaseout of CFCs and other halocarbon emissions and the development of substitutes that minimize or eliminate greenhouse gas emissions.
- ▶ Study in detail the "full social cost pricing" of energy, with a goal of gradually introducing such a system.
- ▶ Improve the efficiency of the U.S. automotive fleet through the use of an appropriate combination of regulation and tax incentives.
- ▶ Make greenhouse warming a key factor in planning for our future energy supply mix.

The Panel considered the different effects of regulation versus incentive oriented methods and policies in determining whether to mandate action or encourage particular behavior. Methods depend on the objective and the seriousness of the problem, thus the Panel decided that the need to reduce future greenhouse gas emissions is strong enough to support the

implementation of **both** regulations and incentive oriented policies that are prudent and cost-effective in the United States.

The panel noted, "The United States should resume full participation in international programs to slow population growth and should contribute its share to their financial and other support." The Panel also believes that by fostering international arrangements nations should be allowed to receive credit for actions taken to reduce or offset emissions in other countries.

Policy Implications of Greenhouse Warming—Report of the Adaptation Panel

Key Points

The Adaptation Panel aimed to "develop an assessment of impacts and adaptation to climate change that emphasized consequences and opportunities for the United States....The tasks were, first, to examine what would happen if climate changed and humanity and nature did not and, second, to find ways to temper any harm and to enhance any benefits of a new climate." The degree to which climate change is a growing factor in environmental policy making depends upon its relation and reaction to other changes; population, land use, environment, wealth, government etc., and the sensitivity of humanity and nature to all of these changes combined.⁵ (The level of sensitivity to climate change would vary among different groups of humans and in different systems in nature; therefore, attention should be put on identifying the most sensitive areas and devising ways to strengthen their adaptability.)

The Panel rated the sensitivity and adaptability of U.S. economic sectors to climate change by assigning a percentage to particular activity sectors, based on their individual contribution to U.S. total national income. In conclusion, it was found that a significant percentage (85%) of U.S. total national income is derived from sectors that would be only moderately impacted by climate change.⁶

Taken into consideration by the Panel was the fact that a communities survive and prosper in a vast range of climates, signifying that societies can cope with wide climatic variations. Technical adaptation was also factored into the equation, because the speed of innovation may exceed that of the projected range of climatic change over the next 50-100 years.

Adaptation Recommendations

- ▶ Increasing research and development programs to study the adaptability of humans and nature to climate change.

⁵ The Adaptation report evaluated the sensitivity of a variety of human activities and natural systems to climate change by considering each activity or system independently. One panelist, Jane Lubchenco, objected to this method, "[classification of activities and systems is] useful as a preliminary organizing framework, but misleading because it implies that the activities and systems are independent and distinct from one another....A comprehensive assessment of the feasibility and cost of adaptations must include the interactions and interdependencies among the various activities and systems."

⁶ The sectors severely impacted by climate change represent less than 5% of U.S. total national income while sectors negligibly effected represent 10% of U.S. total national income.

- ▶ Improving institutions and encouraging governments to strengthen their commitments to devise adaptive strategies.
- ▶ Improving investment in installation of adoptive measures in advance or in anticipation of climate change, especially because many impacts are unknown and will not surface for decades.

Policy Implications of Greenhouse Warming—Report of the Mitigation Panel

Key Points

The Mitigation Panel studied the options for reducing or reversing the onset of potential global warming. The Panel examined the "range of policy interventions that might be employed to mitigate changes in the earth's radiation balance, assessing these options in terms of their expected impacts, cost, and, at least in qualitative terms, their relative cost-effectiveness."⁷ The Panel determined that 10 to 40 percent of current U.S. greenhouse gas emissions can be reduced at low cost.

Through interaction with both the Adaptation and Effects panels, the Mitigation panel had a basis for the accepted magnitude of climatic effects and their overall impacts. The Mitigation Panel also recognized that options must not only be technically feasible, but socially, economically and politically reasonable and acceptable.

The Mitigation Panel assessed current and future energy use and supply trends in many sectors; electricity (residential, commercial and industrial), transportation, building, agriculture, etc., as well as predicted the efficiency potentials of new and improved technologies. A reasonable rate of technological innovation and development, as well as anticipate trends in population growth, deforestation and geoengineering were considered as was the potential impacts of non-energy emissions, for instance; halocarbons, agricultural methane and nitrous oxide.

Mitigating options were considered effective when they were: (1) considered investments in the future of the nation and the planet; (2) cost-effective; and (3) entailed a mixed strategy.

The Mitigation Panel ranked options into three categories: (1) Best-practice or significant potential for mitigating greenhouse warming at low or net cost, often not currently implemented because of various obstacles; (2) relatively costly or more difficult to implement because of hidden or unknown costs and; (3) appear to be feasible with the current level of knowledge, but in need of further research to uncover additional factors and costs.

Cost-Effective and Best-Practice Mitigation Options

- ▶ Improve energy efficiency in the residential, commercial and industrial sectors.

⁷ Mitigating policy is defined as to include programs and specific interventions that might reduce either the rate at which the radiative balance is changing, or the ultimate level at equilibrium, assuming one is reached.

- ▶ Improve vehicle efficiency.

Intermediate Mitigation Options

- ▶ Management of transportation systems.
- ▶ Improve power plant heat rates.
- ▶ Reduce non-energy related emissions.
- ▶ Reforestation.
- ▶ Fuel switch from coal to natural gas.

The least feasible mitigation option, in the near future at least, was geoengineering.

The Panel concluded that the low-cost nature, immediate availability and estimated capability of the energy efficiency measures made their implementation logical.

TECHNOLOGY COOPERATION

WASHINGTON INTERNATIONAL ENERGY GROUP

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2. *The Technology Transfer Process: Background for the U.S. National Energy Strategy*, Pacific Northwest Laboratory, Oak Ridge National Laboratory, and Solar Energy Research Institute, January 1990.
3. *Energy in Developing Countries*, Congressional Office of Technology Assessment, January 1991.
4. *Clean Coal Technology Demonstration Program Update 1990*, United States Department of Energy, February 1991.
5. *Transforming Technology: An Agenda for Environmentally Sustainable Growth in the 21st Century*, World Resources Institute, April 1991.

Technology Cooperation

Overview—Opportunities for U.S. Industry

Despite the current economic downturn, American industry's accomplishments in meeting the twin goals of economic growth and environmental protection have been significant and should serve as a model for economic progress in developing countries, where the potential for economic and environmental mismanagement far exceeds that in the U.S.

This anticipated increase in worldwide energy consumption poses significant challenges in protecting the environment. But, it also presents new business opportunities for America's private sector industries to deploy their economically efficient and environmentally beneficial technologies throughout the world where they are most needed.

A positive approach that would encourage economic growth rather than economic constraint would be an approach that focuses on using cleaner, more efficient technologies in developing countries and transitional economies. Through an expanded technology cooperation program, higher efficiency energy production technologies and management skills could be deployed wherever significant population growth and energy demands are expected.

The key question facing policy-makers should be how American industry—which has pioneered the development of advanced environmental protection technologies—can be positioned to invest its technological and managerial expertise in the economic development of countries where the potential for pollution abatement, and the potential for greenhouse gas emissions reduction, far exceeds that in the U.S.

The United States already has among the lowest rates of greenhouse gas emissions per unit GNP in the world.¹ Greenhouse gas emissions in developed countries as a whole are very low for the value of goods and services produced. By contrast, developing countries and the former centrally planned economies are not nearly as efficient and emit a far greater volume of greenhouse gases per unit of their GNP. The U.S. emits the heating equivalent of 0.2 kilograms of carbon for each dollar of GNP, while Brazil and Indonesia emit the heating equivalent of approximately 2 kilograms for each dollar of GNP, 10 times as much as the U.S. Poland and China each emit the heating equivalent of approximately 1 kilogram of CO₂ for each dollar of GNP.²

Energy demand in the developing world is being spurred by rapid population and inevitable industrial growth. The disparity in emissions per unit of GNP will persist and, in all likelihood, increase—unless more advanced means of producing and using energy are employed worldwide.

According to the International Energy Agency, as much as 85 percent of the projected increase in global CO₂ emissions is expected to be from developing countries. Reductions in emissions by the U.S. and other industrialized countries would quickly be more than offset by this growth.

The world demand for energy is expected to increase significantly by 2005. Based on commitments of OECD countries, placing the burden of CO₂ emissions reduction chiefly on the developed world would only reduce carbon emissions by 314 million tons, an amount equal to only 3 percent of the projected increase.³ Yet, if current electricity demand in developing countries were supplied by modern power plants of the type of "off the shelf" technology already being used in developed countries, the projected increase in global CO₂ emissions would be reduced by about 1 billion tons annually.⁴ Moreover, new advanced technologies, such as those developed through DOE's Clean Coal Technology Program, can reduce emissions from coal-fired power plants by as much as 40 percent per unit of electricity produced.⁵

It is clear that the marginal cost of reducing greenhouse gas emissions by increasing energy efficiency is far less in developing countries than in the developed world.

Elements of a Strong Technology Cooperation Program—What the U.S. is Doing

A technology cooperation program builds on the elements of traditional technology transfer processes where technology, knowledge, and/or information developed in one area is applied and utilized in another. Technology cooperation encompasses needs assessment, technology development, training, and other institution-building mechanisms.⁶ Technology cooperation actively involves all participating countries in the process.

The U.S. is pursuing cooperative initiatives that will make significant contributions to the goal of sustainable development. For example, a new program of the U.S.-Asian Environmental Partnership, recently announced between the U.S. and Asian nations, will open and facilitate a "fertile environmental market" for American technology and remedial services, supported by the Export-Import Bank and other U.S. agencies.⁷ U.S. firms will be assisted in marketing their skills and technologies to this \$300 billion market. Other examples of cooperative initiatives include a DOE project in Poland and the Support for Eastern European Democracies (SEED) Program.

In addition, a number of other programs have performed well. They include AID's Program to Accelerate the Commercialization of Energy Research (PACER), DOE's Committee on Renewable Energy Commerce and Trade (CORECT) and the Multiagency Working Group on Power Sector Innovation (MAGPI).

The federal government's clean coal technology program also has made significant strides in developing technologies that will result in the continued use of America's abundant resources of coal in a manner that will keep an important sector of the domestic economy operating at a productive level while serving the needs of environmental protection.

But, more needs to be done if the U.S. effort to deploy its expertise in the markets of developing countries is to compete effectively with similar efforts already underway by America's economic competitors such as Japan, Germany, France, etc.

Pending U.S. Technology Cooperation Programs

Last year, in addition to introducing legislation to enhance the government's clean coal technology program, Congress and the Bush Administration introduced a number of comprehensive and positive steps to improve the country's technology cooperation effort. In 1992, Congress can complete this work and make it part of a much-needed, comprehensive economic recovery program. Among the pending items:

- ▶ Increase industry participation in research, development and commercialization by encouraging collaborative, cost sharing R&D and making permanent a 20-year tax credit for industrial research and experimentation.
- ▶ Provide copyright protection for technical data and software, both home and abroad, by broadening the scope of the National Cooperative Research Act of 1984.
- ▶ Improve the coordination of federal agencies to export promotion efforts, particularly in Eastern Europe and developing countries.
- ▶ Increase federal funding and participation in technology cooperation and transfer program.
- ▶ Improve the delivery of technology transfer services nationwide through the reform of the infrastructure by ensuring that federal approval for procurement and other technology transfer activities are sufficiently speedy and flexible.

In crafting an effective economic recovery program, Congress and the Administration should further expand programs that encourage the strategic investment of U.S. technology in developing countries and countries in transition. This effort would accomplish three things: create new opportunities for American industry; foster international cooperation on global environmental issues and; help other countries achieve their economic development in a more efficient and environmentally responsible manner.

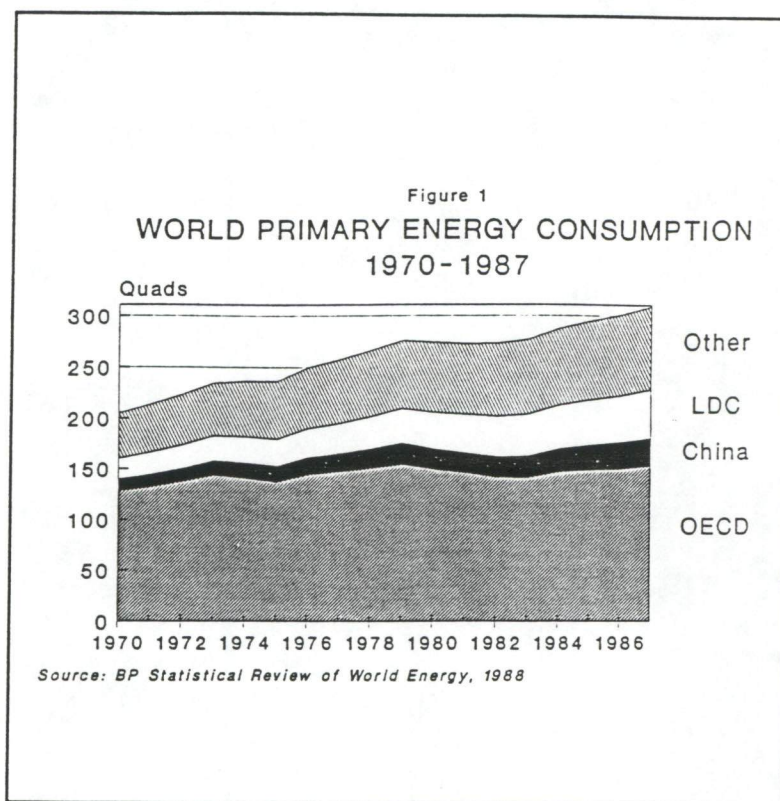
1. World Resources Institute, *World Resources 1990-91*, New York: Oxford University Press, 1990.
2. Ibid.
3. Zimmermeyer, Gunder, *Potentials for CO₂ Reduction as an Example for Prudent Policies to Protect the Climate*, Presented to the International Committee on Coal Research in Washington, D.C., October 1991.
4. Ibid.
5. U.S. DOE Statistics, 1991.
6. Reinstein, Robert, Deputy Assistant Secretary of State for the Environment, Health and Natural Resources, and Chief U.S. INC Negotiator, Statement at the Third INC Framework Convention Session, Nairobi, Kenya, September 1991.
7. "U.S.-Asian Partnership Creating 'Fertile' Environmental Markets," *World Environment Report*, January 7, 1992.

Energy Technology for Developing Countries: Issues for the U.S. National Energy Strategy

Applied Science Division, Lawrence Berkeley Laboratory, University of California, Berkeley, CA, December, 1989.

Key Points

- ▶ *There are continuing shortages of energy for productive uses in many parts of the developing world. Energy is used very inefficiently in all sectors.*
- ▶ *A variety of enhanced energy technology R&D efforts is needed to adequately deal with a host of key developing country energy issues.*
- ▶ *Creation of desirable energy choices and the adoption of improved energy technologies require broad and integrated programs, including substantial emphasis on technology transfer.*
- ▶ *Opportunities exist for greater efforts to promote the use of technologies for more efficient end-use, non-fossil fuel supply, more energy-efficient and environmentally acceptable conversion of fossil fuel.*
- ▶ *DOE has important capabilities to apply in concert with other public and private resources to meet these needs to encourage the adoption by developing nations of improved energy technologies.*



"Developing nations have become a major participant in the world energy economy. As a result, the energy choices made by these nations will be increasingly important in determining the future stresses on the international oil market and global climate. Developing countries also comprise rapidly growing potential markets for U.S. technologies."

"In 1970 the developing countries of the world consumed about 16 percent of the world's commercial sources of energy; currently they consume about 25 percent. This energy growth has not been without substantial problems. There are continuing shortages of energy for productive uses in many parts of the developing world. Energy is used very inefficiently in all sectors."

"Numerous international and governmental agencies play a major role in providing loans and assistance to developing countries. The energy-related loans of the World Bank have grown to an annual level of \$4 billion in recent years. Most of these loans are for power generation."

"The (U.S.) Department of Energy has been active in concluding international agreements for cooperative programs with a variety of countries concerning numerous energy technologies."

"We have identified technical assistance for energy on the order of \$200 to \$300 million per year from the AID, the United Nations organizations, and ESMAP."

"There are significant barriers to the effective transfer of technology to developing countries. Many of these are of an institutional nature: the policy environment is poorly developed, energy prices are held artificially low, hard currency for the purchase of technology is not available, and institutions are not in place to permit effective implementation of technology."

"Nonetheless, there have been important cases of successful transfer of technologies and capabilities to developing countries. Many of these have been in the area of energy efficiency, where the economic benefits have been apparent. Renewable energy technologies, especially in remote areas have seen successes."

Conclusions

- ▶ "A variety of enhanced energy technology R&D efforts is needed to adequately deal with a host of key developing country energy issues."
- ▶ "Creation of desirable energy choices and the adoption of improved energy technologies require broad and integrated programs, including substantial emphasis on technology transfer."

- ▶ "Opportunities exist for greater efforts to promote the use of technologies for more efficient end-use, non-fossil fuel supply, more energy-efficient and environmentally acceptable conversion of fossil fuel.
- ▶ "DOE has important capabilities to apply in concert with other public and private resources to meet these needs to encourage the adoption by developing nations of improved energy technologies."

The Technology Transfer Process: Background for the U.S. National Energy Strategy

Pacific Northwest Laboratory, Oak Ridge National Laboratory and Solar Energy Research Institute, January, 1990.

Key Points

- ▶ *"Successful technology transfer results when strategies are designed to use a variety of mechanisms, especially those mechanisms that have a feedback element. Personal contact is an essential element in transferring complex scientific knowledge, introducing a new product into the market, enhancing user acceptance and encouraging results."*
- ▶ *"The technology 'champion' cannot be overvalued. All technologies must overcome many barriers before completing their objective. Even when a technology is transferred, it will need a 'champion' in the new organization."*
- ▶ *"A good technology transfer strategy shortens the time and minimizes the information loss associated with the transfer."*
- ▶ *"Separating the performance of a technology from the performance of its technology transfer program is difficult. A technology transfer program must be judged in terms of its original objective. Sometimes the technology itself is so developed that the technology transfer strategy can only marginally affect its rapid acceptance. sometimes a technology is so undeveloped that the best prepared technology transfer strategy cannot affect its rejection."*
- ▶ *"Further research, including documentation of failures, would increase understanding of the role of mechanisms, strategies and timing. The lack of documentation on failures has led to a major loss of historical data, from which valuable lessons could be learned."*

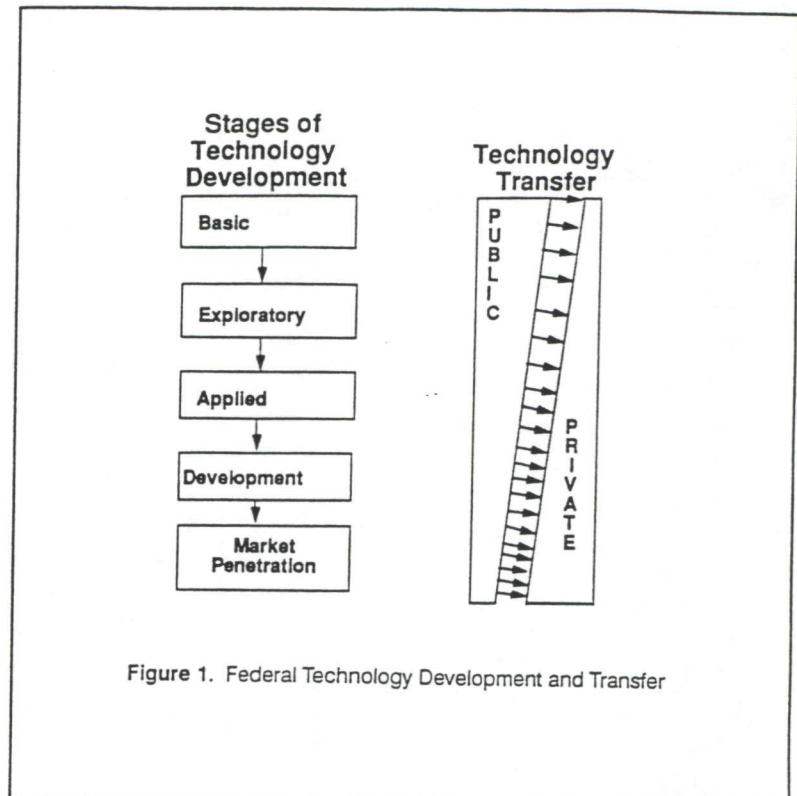
"Technology transfer... (is) the process by which technology, knowledge, and/or information developed in one organization, in one area, or for one purpose is applied and utilized in another organization, in another area, or for another purpose. The end user may be the public, industry, another federal laboratory, or any other technology developer. Technology information can be a simple energy conservation practice for public use, data bases, a patent of an invention, a report on the properties of a magnetic field, an improved industrial process, or a new procedure for handling a hazardous material. The mechanisms that developers

throughout government and industry use to transfer technology can be grouped into eight broad categories:

- ▶ advisory groups
- ▶ research collaboration
- ▶ personnel exchanges
- ▶ technical assistance
- ▶ licensing
- ▶ spinoff companies
- ▶ information dissemination
- ▶ education"

"Targeting the audience for any technology transfer effort increases the efficiency of the effort. User facilities are an example of one-on-one transfer of technical information to a targeted group of technical people working in a related field."

"Many legal, institutional and cultural barriers hinder successful transfer. The role of the technology's champion, frequently not the original developer, is important in overcoming the barriers to transferring the technology to the end user. Many people with experience in the process say that technology transfer requires repeated face-to-face communication. Effective transfer involves feedback from people dealing with people, not just publishing reports."



Energy in Developing Countries

Office of Technology Assessment, U.S. Congress, January, 1991.

Key Points

- ▶ ***International efforts to control greenhouse gas emissions require active participation by developing countries. Many developing countries could be adversely affected by climate change, some much more than most industrial nations.***
- ▶ ***An economically and environmentally sound approach to energy development offers potentially large benefits both for the developing countries and for the rest of the world. It can contribute to economic growth in the developing countries, leading to higher living standards, reduction of hunger and poverty, and better environmental conditions.***
- ▶ ***A fundamental constraint on environmental policy-making in all but a handful of developing countries is the absence of systematic, integrated data on the current state of environmental pollution and degradation.***

"Energy use in developing countries has risen more than fourfold over the past three decades and is expected to continue increasing rapidly in the future."

"The rapid growth of energy use in developing countries has wide impacts. The economic development process has traditionally been accompanied by rapid increases in oil demand, which, together with rising demand in the industrial countries, contribute to upward pressures on world oil prices. High levels of indebtedness in the developing countries, partly energy-related, have already contributed to instability in the international monetary and banking system. Rapid increases in fossil fuel use in developing countries also represent a growing contribution to the increase in local and regional air pollution as well as atmospheric concentrations of greenhouse gases such as carbon dioxide. International efforts to control greenhouse gas emissions require active participation by developing countries. Many developing countries could be adversely affected by climate change, some much more than most industrial nations."

"An economically and environmentally sound approach to energy development offers potentially large benefits both for the developing countries and for the rest of the world. It can contribute to economic growth in the developing countries, leading to higher living standards, reduction of hunger and poverty, and better environmental quality."

"Responses to the deteriorating quality of the environment in developing countries show a mixed picture. On the one hand, progress is being made in setting up the government apparatus of environmental control, and concern and activity at the grassroots level is rising rapidly. On the other hand, implementation of environmental policies is frequently difficult to achieve, and progress is sometimes impeded by unintended environmental impacts of other policies."

"The past two decades have seen considerable environmental policy-making activity in the developing world, including the establishment of national environmental agencies and organizations and the adoption of laws and practices designed to prevent environmental pollution and degradation or to protect unique natural environments and wildlife. All in all, more than 100 developing countries now have governmental bodies whose responsibilities include environmental protection. However, only a limited number of countries have established independent environmental agencies in their central governments. Most have increased their environmental oversight capabilities by creating or expanding sections or offices within environment-related government departments such as agriculture, energy, fisheries, forestry, irrigation, natural resources or tourism."

"The larger developing nations with traditions of extensive government policy-making and implementation and a relatively advanced domestic research base have formulated and adopted a variety of environmental protection laws and standards, including the requirement of environmental impact statements for large projects. Developing countries with detailed nationwide air and water quality standards or with regulations specifying the levels of permissible pesticide residues in food are still, however, in the minority. Those that do have such regulations have usually based their legislation on the standards in force in the industrialized nations; consequently, their specifications—at least on paper—are usually as strict as and sometimes even stricter than, those of the industrial countries, although implementation may lag."

"Some developing countries have shown a significant commitment to protecting the environment. China's most polluted coal-burning cities have mean sulfur dioxide levels between 100 and 300 $\mu\text{g}/\text{m}^2$, about the same as in British cities prior to the introduction of Britain's Clean Air Act in the early 1950's. China, with levels of income much lower than the United Kingdom in the early 1950's, has already begun to respond to the problem by introducing cleaner urban fuels and outfitting coal-fired plants with effective particulate controls."

"Many developing countries have also experienced an increase in grassroots environmentalism in addition to official activity. In Ecuador, Colombia, Guatemala, and Brazil movements organized by citizen groups have led to the banning of toxic pesticides and the initiation of major urban cleanups. Indigenous nongovernmental organizations (NGOs) have increasingly involved themselves in environmentally oriented efforts. More than 600 Brazilian and

Indonesian NGOs currently are working on environmental issues, as are several thousand groups in India."

"Despite these achievements, major problems remain. A fundamental constraint on environmental policymaking in all but a handful of developing countries is the absence of systematic, integrated data on the current state of environmental pollution and degradation. While there is sometimes a great deal of site-specific information connected with particular projects, virtually all the developing countries lack spatially representative networks for monitoring land, water, and air quality or accurately measuring the rates of deforestation or changes in agricultural land and soil quality. China and India, however, have accumulated a fairly extensive information base through the combined activities of various government departments and university researchers."

Clean Coal Technology Demonstration Program Update 1990

U.S. Department of Energy, February, 1991.

Key Points

- ▶ *"Clean coal technologies can play a role in reducing emissions of greenhouse gases. Because some of these technologies (such as pressurized fluidized beds, integrated gasification combined cycles, and fuel cells) improve efficiency of the conversion of coal to useful energy, less CO₂ is emitted per unit of useful energy produced. If global climate change is substantiated and reduction in emissions of greenhouse gases becomes a national policy objective, then worldwide commercial deployment of clean coal technologies would assume added significance."*
- ▶ *"In order for coal to compete with oil and gas, the following are required:*
 - "Continuing contributions to the technology base for clean coal use*
 - "Broadening opportunities to choose coal as a fuel*
 - "Ensuring balanced environmental programs*
 - "Removing barriers to improving the efficiency of the coal supply infrastructure."*
- ▶ *"New clean coal technologies can be major factors in making exported U.S. coal attractive in other countries. These new technologies may provide the single most important advantage that the United States could have in the global competition for new markets."*

"The CCT Program is developing advanced coal-based technologies that offer numerous options for addressing a wide range of energy issues, including acid rain, global climate change, improved energy efficiency, energy security, and environmental quality. Although coal's abundance makes it one of the nation's most important strategic resources in building a more secure energy future, the characteristics of coal have tended to inhibit its greater use as a fuel."

"For coal to reach its full potential, environmentally responsive, economically competitive, advanced coal-using technologies and systems must be developed—and they must be responsive to diverse energy markets and varied consumer needs."

"The (CCT) program is a key component of a strategy conceived to reduce or eliminate the economic and environmental barriers that limit the full consideration of coal as an energy resource. These barriers result from the interrelationships of a number of complex issues, including the following:

Air Quality

"Passage of the first Clean Air Act of 1970 and its subsequent amendments set the United States on a course that has committed billions of dollars to protecting the environment. The Environmental Protection Agency (EPA) has estimated that U.S. industry had expended well over \$250 billion to control air emissions since enactment of air quality legislation in 1970."

"Much of this has been spent by electric utilities, particularly those using coal to generate power. Since 1975, U.S. utilities have spent more than \$100 billion for SO₂ capture alone. An average of \$8 billion a year has been spent by coal-burning utilities to comply with air quality standards."

"As a result of these air quality expenditures, SO₂ emissions have declined dramatically. Between 1970, when the first Clean Air Act was passed, and 1988, nationwide SO₂ emissions from all anthropogenic sources have dropped by 28-30 percent. This decline in emissions has occurred even as coal use was soaring: while SO₂ emissions were falling, U.S. electric utilities were increasing their coal consumption by nearly 80 percent. Most of the decline in SO₂ emissions results from electric utility plants (1) switching to coals with lower sulfur content, (2) installing flue gas desulfurization systems, and (3) decreasing the use of some high emission plants."

Acid Rain

"With the passage of the Clean Air Act Amendments of 1990 (Public Law 101-549), stringent measures have been mandated to control the emissions of the principal acid rain precursors, sulfur dioxide (SO₂) and nitrogen oxides (Nox). The act will require electric utilities to increase their operating costs by \$4-5 billion annually by the year 2000 to comply. This legislation will further reduce SO₂ emissions to 50 percent of their 1980 levels by the year 2000, and it will cap SO₂ emissions at that level. (This will result in a constant emissions level allowed from all electric utility generation units of 8.9 million tons per year). In addition, by the year 2000, the act will require installation of the best available Nox control devices on existing coal-fired electric utility power plants as defined by EPA."

"Continued increases in the use of coal, while successfully achieving the required reductions in emissions, will require the availability and use of more advanced and more efficient emissions control technologies. These technologies will be available only through the demonstration, development and commercialization of advanced innovative concepts, processes and equipment. The CCT Program provides the means whereby a suite of these technologies will be available to help solve U.S. emissions problems while allowing the continued use of coal, the most abundant U.S. energy source."

Global Climate Change

"One of the critical environmental issues gaining international attention is the possibility of changes in global climate as a consequence of changes in atmospheric concentrations of "greenhouse" gases--most notably carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons. Between 1960 and 1986, the atmospheric concentration of carbon dioxide (CO₂) increased by nearly 10 percent worldwide. The increased concentration has been attributed primarily to the combustion of fossil fuels and global deforestation. In 1986, the burning of fossil fuels in the United States accounted for 22 percent of the global CO₂ emissions. Of this U.S. portion, electric power generation contributed 35 percent, transportation 30 percent, industrial sources 24 percent, and residential and commercial sectors 11 percent. It is estimated that coal combustion accounts for approximately 36 percent of the CO₂ emitted in the United States. In other words, U.S. coal use accounts for 8 percent of global CO₂ emissions from the combustion of fossil fuels."

"Whether the earth's climate is changing because of the generation of greenhouse gases is still matter of debate and scientific analyses. Moreover, there are significant questions about the relative contributions of various human activities. Nevertheless, if scientific evidence ultimately shows that remedial actions are necessary to mitigate climatic change, technological modernization is among the alternative strategies for reducing emissions."

"Clean coal technologies can play a role in reducing emissions of greenhouse gases. Because some of these technologies (such as pressurized fluidized beds, integrated gasification combined cycles, and fuel cells) improve efficiency of the conversion of coal to useful energy, less CO₂ is emitted per unit of useful energy produced. If global climate change is substantiated and reduction in emissions of greenhouse gases becomes a national policy objective, then worldwide commercial deployment of clean coal technologies would assume added significance."

Power Production

"Currently more than half of the electricity generated in this country is produced by coal-burning power plants. Several trends in the utility sector are converging at the same time that environmental requirements for new power plants are becoming increasingly stringent, together making demonstrations of the commercial applicability of clean coal technologies increasingly important."

"Until 1970, the utility industry was experiencing a real dollar decrease in the cost of electricity, due primarily to the development of improved power conversion equipment and economies of scale. But by 1970, economies of scale had been exploited to the limit, and metallurgical limits prevented the use of higher temperatures and pressures as means for improving plant efficiencies. Since 1970, conventional emissions control systems have added to the cost and complexity of plant operation."

"Since the passage of the Clean Air Act of 1970, Prevention of Significant Deterioration (PSD) regulations have increased the time required to obtain permits for major new sources of emissions. In addition, the Clean Air Act Amendments of 1977 introduced nonattainment area requirements for new sources, in many cases setting emissions levels for individual laws that are more stringent than national emissions standards. In other words, law constraints on existing lands are more lenient, set by State Implementation Plans (SIP), rather than by New Source Performance Standards."

"These factors, together with others that have dramatically increased the costs of new plant construction, have created an incentive for plant operators to keep existing plants in service as long as possible. Life extension has become a priority for the utility industry, which is seeking low-cost approaches to keeping up with increasing demand."

"The utility industry has been confronted by the limits of the state of the art of technologies currently available. Prior to advances in clean coal technologies, the utility industry's options for controlling SO₂ emissions from coal-fired units have been limited to coal cleaning, coal switching (burning coals with lower sulfur content), and conventional scrubbers."

"The 1990s will be critical for the development of new energy options that meet U.S. energy, economic, and environmental goals. Coal remains the fuel of choice for most baseload electric utility capacity; its lower fuel costs (relative to oil and natural gas) more than offset its higher capital costs. Today, coal-burning power plants produce 56 percent of the electricity generated in the United States. (In fact, electric utilities consume almost 80 percent of U.S. mined coal. The remaining 20 percent is used in

industrial applications, as metallurgical coal, or is exported.) By the year 2010, coal is projected to constitute over 60 percent of the energy consumed by electric utilities, thereby accounting for most of the projected growth in U.S. coal demand; utility consumption of coal is forecast to grow from 14.5 quads in 1986 to 25 quads in 2010."

"For this growth to occur, however, potential users must be confident that (1) coal prices are predictable; (2) coal-burning and associated pollution control equipment are available, cost-effective, and reliable; and (3) financial incentives are adequate for risking higher capital investments."

"The electric utility industry stands at the threshold of a fundamental change in the technological base of power generation, just as the CCT Program is getting under way. By the mid-1990s, many utilities will be confronted by the dual problem of an aging boiler inventory and the potential long-term need for increasing their power-generating capacity. By the year 2000, 44 percent of the nation's coal-fired capacity will be at least 30 years old. Utility decision makers will have to make fundamental choices to retire, refurbish, repower, or replace many of these units."

"The past decade has brought substantial changes in traditional electric power generation. These changes, including independent power production, qualifying facilities, and cogeneration, are all supported by regulatory provisions and can have a pronounced effect on the market for clean coal technologies. Proposed regulations have the potential to increase the availability, diversity, and competitiveness of alternative sources of power purchased by utilities. They also have the potential to increase the client base for clean coal technologies beyond the traditional utility industry, thus opening new opportunities and markets."

Energy Security

"The nation's recoverable coal reserves totalling 268 billion tons are sufficient--at even double today's rates of production--to last well into the 21st century and beyond, making coal one of the most important U.S. resources in building a more secure energy future. With current prices and technology, U.S. recoverable reserves of coal could supply the nation's coal consumption at current rates for nearly 300 years."

"Any effort to increase coal's use beyond forecasted levels must be directed primarily toward expansion into new markets while increasing its competitiveness in traditional markets. Although lower coal prices would promote some increase in consumption, more substantial demand increases are currently hindered by various technical, regulatory, environmental, and other obstacles."

"In DOE's examination of energy-related security interests, coal is recognized as having substantial potential to reduce dependence on imported oil and to enhance energy security. In order for coal to compete with oil and gas, the following are required:

- ▶ Continuing contributions to the technology base for clean coal use
- ▶ Broadening opportunities to choose coal as a fuel
- ▶ Ensuring balanced environmental programs
- ▶ Removing barriers to improving the efficiency of the coal supply infrastructure

The technologies being developed in the CCT program contribute solutions for all but the last of these needs."

International Competitiveness

"New clean coal technologies can be major factors in making exported U.S. coal attractive in other countries. These new technologies may provide the single most important advantage that the United States could have in the global competition for new markets."

"The advantage of advanced clean coal technologies in supplying the demand for better equipment is clear when it is recognized that cost of the coal combustion technologies on the market were developed prior to 1940. The older technology cannot compete with the efficiency or lower emissions of modern fluidized-bed boilers or other advanced combustion or conversion concepts."

"Hardware and power-generating concepts relating to coal combustors, gas cleanup, advanced sensors, instrumentation, diagnostics, and repowering technologies (e.g., pressurized fluidized beds and gasification combined cycles) can be effective marketing tools when packaged with the coal itself. The ability to show a prospective international customer an actual operating facility running on U.S. coal, rather than just a drawing-board concept or engineering prototype, could be a very persuasive argument for international consumers to buy a U.S.-proven clean coal technology. The opportunity is consistent with and recognizes the increasing demand for a safe, effective technology that does not impose further burdens on environmental quality."

"Through the year 2000, energy consumption in the European countries of the Organization for Economic Cooperation and Development (OECD), Japan, and developing countries combined is projected to grow significantly faster than in the

United States. The continuing changes occurring in Eastern Europe also provide substantial and significant opportunities for U.S. industry, including the vendors of those technologies being developed by the CCT program."

"The nations of Western Europe and Japan are establishing stringent environmental regulations. Abatement technologies are of interest as alternatives to using lower sulfur coal as a means of controlling emissions. IEA has projected that Western Europe will require 265 gigawatts of new electric capacity by the year 2000; of this, approximately 44 gigawatts will be coal-fired capacity. As in other regions of the world, the dramatic social and political changes occurring in Eastern Europe will almost certainly be accompanied by increasing demands for energy. The large projected growth in worldwide energy consumption, together with the increasing demand for pollution abatement, offers a potentially sizable market for U.S. exports of clean coal, clean coal-based fuels, and clean coal-burning technologies and new energy supplies. The benefits that clean coal technologies offer in reducing energy and environmental conflicts in North America can also be offered to the rest of the world."

The Technologies

"The term "clean coal technology" refers to a new generation of advanced coal utilization technologies that are environmentally cleaner and in many cases more efficient and less costly than conventional coal-using processes. These new energy and pollution control systems are the products of years of research and development in hundreds of government and private laboratories throughout the world. Commercial demonstration of these technologies is the final step from the research laboratory to the marketplace. Clean coal technologies offer the potential for a cleaner environment and lower power costs by contributing to the resolution of issues relating to acid rain, global climate change, future energy needs and energy security."

"Clean coal technologies can reduce emissions of SO₂, Nox, and other pollutants at three major points along the path that coal generally follows from a mine to a power plant or factory:

1. **Precombustion Stage.** Plants physically, chemically, or biologically clean the coal by removing pollutants before the coal is burned.
2. **Combustion Stage.** The way coal burns is modified, or pollutant-absorbing substances are injected into the combustion chamber.
3. **Postcombustion Stage.** Devices remove pollutants from the flue gases exiting the boiler.'

"Coal conversion represents a fourth means of using coal cleanly; it is a departure from traditional coal-burning methods in that the coal is converted into a gas or liquid that can be cleaned and then used as a fuel."

Transforming Technology: An Agenda for Environmentally Sustainable Growth in the 21st Century

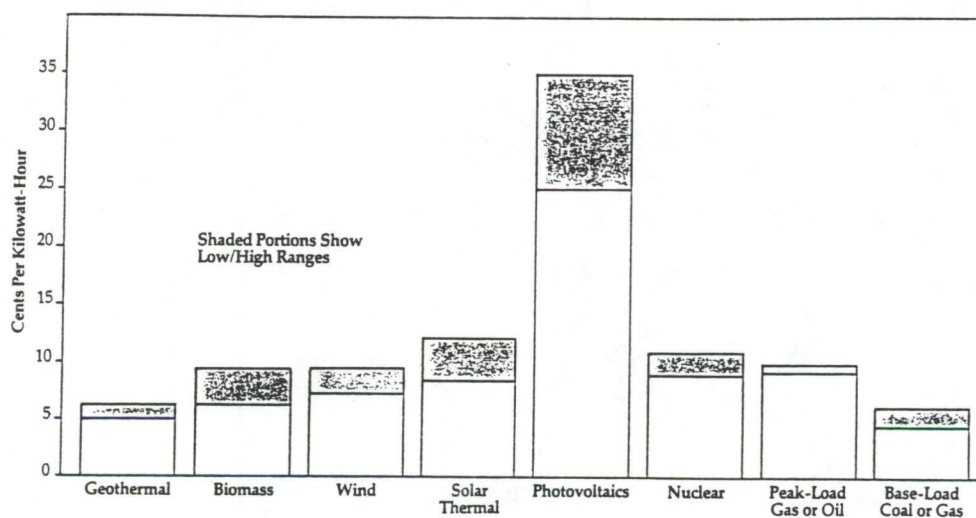
World Resources Institute, April, 1991.

Key Points

- ▶ *"Environmental regulation should be reformed to encourage technological change."*
- ▶ *"Economic incentives should be employed in tandem with regulation to encourage technological transformation."*
- ▶ *"Rapid dissemination of clean technologies from the industrial countries to the developing and formerly centrally planned countries where over 80% of humanity lives and where much of the globe's economic and population growth will occur is vital for technological transformation."*
- ▶ *"Environmentally affirmative corporate leadership is likely to be a stronger force for technological change than public policies."*

The Institute claims that two decades of environmental regulation in the industrialized countries have yielded some results, but also demonstrate the limitation of current approaches. They feel that increasing the resource efficiency of production by following the above steps is the best course of action.

Figure 5. Electricity Costs for New Generating Capacity



Source: United States Department of Energy, (1990)

CHRONOLOGICAL BIBLIOGRAPHY

WASHINGTON INTERNATIONAL ENERGY GROUP

Chronological Bibliography¹

Economics

June 25, 1987: Lazzari, Salvatore, "Energy Tax Options to Increase Federal Revenue," Report for Congress, Congressional Research Service.

June 7, 1988: Lazzari, Salvatore, "A History of Federal Energy Tax Policy: Conventional as Compared to Renewable and Nonconventional Energy Resources," Report for Congress, Congressional Research Service.

1990: "World Resources 1990-91 Guide to the Global Environment," World Resources Institute in Collaboration with the United Nations Environment Programme and the United Nations Development Programme.

February 1990: Manne, Alan S. and Richard G. Richels, "Global CO₂ Emission Reductions—the Impacts of Rising Energy Costs," Stanford University and the Electric Power Research Institute.

February 5, 1990: Nordhaus, William D., "To Slow or Not to Slow: the Economics of the Greenhouse Effect," Partial Support by National Science Foundation.

April 19, 1990: Center for Strategic and International Studies Team, "The Cost of Stabilizing Global Climate: Phase II," Status Report, Global Climate Coalition Steering Committee.

May 1990: "Economics and Global Change: New Haven Workshop," Proceedings, National Oceanic and Atmospheric Administration, National Science Foundation, National Aeronautics and Space Administration.

June 1990: "Energy Use and the U.S. Economy," Background Paper, Office of Technology Assessment.

June 13, 1990: Jorgenson, Dale W. and Peter J. Wilcoxon, "Global Change, Energy Prices, and U.S. Economic Growth," Harvard University.

July 6, 1990: Gale, Roger W., "A Carbon Tax Could Blacken Economy," *Wall Street Journal*.

¹ The **Chronological Bibliography** is arranged by date and by subject (economics, science, policy and technology cooperation) in order to facilitate convenient updating and revision. Consequently, the reports, articles, conference proceedings, etc., do not follow a traditional bibliographic format.

August 1990: "Carbon Charges as a Response to Global Warming: the Effects of Taxing Fossil Fuels," Congressional Budget Office.

August 1990: Montgomery, W. David, "Effects on Energy Markets and the U.S. Economy of Measures to Reduce CO₂ Emissions from Fossil Fuels," Congressional Budget Office.

September 1990: "The Economics of Long-Term Global Climate Change: A Preliminary Assessment," U.S. Government Interagency Task Force, Office of Policy, Planning & Analysis, U.S. Department of Energy.

September 1990: Jorgenson, Dale W. and Peter J. Wilcoxon, "The Cost of Controlling U.S. Carbon Dioxide Emissions," Harvard University.

October 22-23, 1990: "Economic/Energy/Environmental Modeling for Climate Policy Analysis," Conference Proceedings, Sponsored by University of Tokyo and Massachusetts Institute of Technology.

November 1990: Manne, Alan S. and Richard G. Richels, "Buying Greenhouse Insurance," Stanford University and Electric Power Research Institute.

December 1990: Jorgenson, Dale W. and Peter J. Wilcoxon, "Reducing U.S. Carbon Dioxide Emissions: the Cost of Different Goals," Harvard University.

December 4, 1990: Cristofaro, Alex, "The Cost of Reducing Greenhouse Gas Emissions in the United States," Air and Energy Policy Division, Environmental Protection Agency.

December 13, 1990: "Economic Effect of Alternative Climate Change Policies," Center for Strategic and International Studies, Putnam, Hayes & Bartlett, International Resources Group, The Brock Group, and DRI/McGraw-Hill.

1991: White, James C., Editor, "Global Climate Change: The Economic Costs of Mitigation and Adaptation," Publisher Unknown.

1991: "The Economic Impact of Coal," Special Report, *Coal Voice*, National Coal Association.

February 1991: "Energy Use and Emissions of Carbon Dioxide: Federal Spending and Credit Programs and Tax Policies," Congressional Budget Office.

March 5, 1991: Clarke, John F., "Global Environmental Change: Where Have We Been? Where Do We Go From Here?" Global Climate Change Forum, United States Energy Association.

April 1991: "The Economic Effects of Restrictions on Coal and Petroleum Fuels in Stationary Uses," Report for the U.S. Department of Commerce, DRI/McGraw-Hill.

May 21-22, 1991: "U.S. Perspectives on Environmental Protection and Economic Development," The Atlantic Council.

June 1991: Gale, Roger W., "Environmental Initiatives Based on the U.S. Clean Air Act Amendments," Speech Before the World Energy Conference, Asia-Pacific Region.

September 1991: "Limiting Net Greenhouse Gas Emissions in the United States: Report to the Congress of the United States," Executive Summary, Office of Environmental Analysis, Deputy Under Secretary for Policy, Planning and Analysis, U.S. Department of Energy.

September 1991: "Limiting Net Greenhouse Gas Emissions in the United States: Report to the Congress of the United States," Volume One, Office of Environmental Analysis, Deputy Under Secretary for Policy, Planning and Analysis, U.S. Department of Energy.

September 1991: "Limiting Net Greenhouse Gas Emissions in the United States: Report to the Congress of the United States," Volume Two, Office of Environmental Analysis, Deputy Under Secretary for Policy, Planning and Analysis, U.S. Department of Energy.

October 10, 1991: Gale, Roger W., "The Economic Impact of Global Warming: Competitiveness is at Stake," Speech Before the 17th Annual Electric Utility Conference.

November 1991: "OECD Economic Surveys: United States 1990-91," Organization for Economic Cooperation and Development.

December 1991: Montgomery, W. David, "The Cost of Controlling Carbon Dioxide Emissions," Charles River Associates.

January 10, 1992: Holden, Constance, Editor, "Briefings: Greenhouse Gas Tax," *Science*.

Science

Date Unknown: "The Greening of Planet Earth: The Effects of Carbon Dioxide on the Biosphere," Video, Institute for Biospheric Research.

Date Unknown: Carr, R., "Population as a Cause of Global Warming," Environmental Briefing Piece, Publisher Unknown.

1982: Craig, H. and C.C. Chou, "Geophysics Research Letter 9," *Geophysics*.

November 1988: "Background Facts and Perspective on the Greenhouse Effect," Science Concepts, Inc.

1989: "Scientific Perspectives on the Greenhouse Problem," George C. Marshall Institute.

February 1989: Mitchell, John F.B., "The 'Greenhouse' Effect and Climate Change," *Review of Geophysics*, 27 1 February 1989, pp. 115-139, American Geophysical Union.

July 1989: Sullivan, K.M., "The Effect of CO₂ Emissions from Coal Fired Power Plants," The World Coal Institute.

August 1989: Bradley, Raymond S., Henry F. Diaz, Thomas R. Karl, J. Dan Tarpley, Robert G. Quayle, and David A. Robinson, "The Recent Climate Record: What It Can and Cannot Tell Us," *Review of Geophysics*, 27 3 August 1989, pp. 405-430, American Geophysical Union.

August 8, 1989: "Global Climate Change," Section of Natural Resources, Energy, and Environmental Law, American Bar Association.

October 1989: Spencer, R.W., Text of a Letter to T.R. Karl.

December 1989: Smith, Joel B. and Dennis Tirpak, "The Potential Effects of Global Climate Change on the United States," Report to Congress, Office of Research and Development, Office of Policy, Planning, and Evaluation, U.S. Environmental Protection Agency.

1990: "Strategies for Adaption to Sea-Level Rise," Coastal Zone Management Subgroup, Intergovernmental Panel on Climate Change, World Meteorological Organization and United Nations Environment Programme.

1990: "Studies in Geophysics: Sea-Level Change," Geophysics Study Committee, Commission on Physical Sciences, Mathematics, and Resources, National Research Council, National Academy Press.

1990: Meier, Mark F., "Role of Land in Present and Future Sea Level Change," University of Colorado.

February 1990: "Energy and Climate Change: Report of the U.S. Department of Energy Multi-Laboratory Climate Change Committee (Lawrence Livermore National Laboratory, Argonne National Laboratory, Battelle Pacific Northwest Laboratory, Brookhaven National Laboratory, Idaho National Engineering Laboratory, Lawrence Berkeley Laboratory, Los Alamos National Laboratory, Oak Ridge National Laboratory, Sandia National Laboratory), Lawrence Livermore National Laboratory.

March 1990: Morrison, Robert E., "Global Climate Change and the Greenhouse Effect: Predictions and Uncertainties," Report for Congress, Science Policy Research Division, Congressional Research Service.

March 30, 1990: Spencer, Roy, "Precise Measurements of Global Temperature Trends from Satellites," *Science*.

September 28, 1990: Michaels, Patrick J., University of Virginia, "Remarks by the Chemical Manufacturers Association (September 27, 1990), Maryland Chemical Industry Council (October 4, 1990), Kentucky Coal Operators Association (October 9, 1990), Amvest Corporation Annual Meeting (October 22, 1990), Council of Industrial Boiler Owners (October 25, 1990)," Summary, Submitted to *Science*.

1991: "Climate Change: The IPCC Response Strategies," Intergovernmental Panel on Climate Change, World Meteorological Organization and United Nations Environment Programme, Island Press.

Winter 1991: "Reports to the Nation on Our Changing Planet: The Climate System," Office for Interdisciplinary Earth Studies, UCAR and Office of Global Problems, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

September 23, 1991: Singer, S. Fred, "No Scientific Consensus on Greenhouse Warming," *Wall Street Journal*.

October 8, 1991: Lindzen, Richard S. and Alfred P. Sloan, Massachusetts Institute of Technology, "Statement to the House Committee on Science, Space and Technology.

November 1991: Analysis by Dr. Eigil Friis-Christensen and Dr. Knud Lassen of the Danish Meteorological Institute in Copenhagen, *Science*.

November 19, 1991: Idso, Sherwood, Testimony Before the California Energy Commission.

December 1991: Karl, Tom, "Global Warming Evidence for Asymmetrical Diurnal Temperature Change," National Oceanographic and Atmospheric Administration.

December 1991: Zaburunov, Steven A., "As the World Breathes: The Carbon Dioxide Cycle," *Earth*, Vol. 1 No. 1 January 1992, pp. 26-33.

December 1991: "Global Warming," Press Release, Worldwatch Institute.

December 24, 1991: Stevens, William K., "Earth's Temperature Has Dropped a Little After a Warm Spell," *New York Times*.

January 15, 1992: Conversation with David Aubrey, Woods Hole Institution.

January 21, 1992: Stevens, William K., "Scientists Suggest Global Warming Could Hasten the Next Ice Age," *New York Times*.

Policy

Date Unknown: Laming, Richard, "U.S. Challenge to Prevailing Greenhouse Wisdom," Excerpt from *Scientific Perspectives on the Greenhouse Problem*, George C. Marshall Institute.

Date Unknown: Lord Haslam, Chairman of British Coal, "Statement of 1989-90 Results," British Coal.

1989: Schneider, Stephen H., National Center for Atmospheric Research, "Global Warming: Are We Entering the Greenhouse Century," Sierra Club.

1989: DeFries, Ruth S. and Thomas F. Malone, "Global Change and Our Common Future: Papers from a Forum," Proceedings, Committee on Global Change, National Research Council, National Academy Press.

1989: "Energy and the Environment: Policy Overview," International Energy Agency.

February 1989: Ashton, W.B., H.C. Cheng, J.A. Edmonds, M. Steinberg, "A Preliminary Analysis of U.S. CO₂ Emissions Reduction Potential from Energy Conservation and the Substitution of Natural Gas for Coal in the Period to 2010," Prepared for the U.S. Department of Energy, Brookhaven National Laboratory.

February 1989: Lashof, Daniel A. and Dennis A. Tirpak, "Policy Options for Stabilizing Global Climate," Draft Report to Congress, Executive Summary, Office of Policy, Planning and Evaluation, U.S. Environmental Protection Agency.

May 4, 1989: "Symposium on Global Climate Change: Private Sector Implications," Proceedings, International Environment Bureau, International Chamber of Commerce.

June 13, 1989: "Global Warming & the Future of Texas Agriculture," Speech by Sen. Hightower and Related News Release, "Hightower Urges Texas Policy Responses to Global Warming," Office of Natural Resources, Texas Department of Agriculture.

July 1989: "Our Changing Planet: The FY 1990 Research Plan," The U.S. Global Change Research Program, Committee on Earth Sciences, Office of Science and Technology Policy, Executive Office of the President.

July 1989: "Carbon Dioxide Reduction through Electrification of the Industrial and Transportation Sectors," Executive Summary, Prepared for Edison Electric Institute by Energy Research Group, Inc.

October 1989: "A Compendium of Options for Government Policy to Encourage Private Sector Responses to Potential Climate Change," Executive Summary, Report to Congress, Office of Environmental Analysis, Assistant Secretary for Environment, Safety, and Health, U.S. Department of Energy.

October 1989: "A Compendium of Options for Government Policy to Encourage Private Sector Responses to Potential Climate Change, Volume One: Methodological Justification and Generic Policy Instruments," Report to Congress, Office of Environmental Analysis, Assistant Secretary for Environment, Safety, and Health, U.S. Department of Energy.

October 1989: "A Compendium of Options for Government Policy to Encourage Private Sector Responses to Potential Climate Change, Volume Two: Policy Options by Sector and Considerations for Assembling a Policy Package," Report to Congress, Office of Environmental Analysis, Assistant Secretary for Environment, Safety, and Health, U.S. Department of Energy.

November 1989: Various Contributors, "Task Force on Greenhouse Effect," Ontario Hydro.

December 14, 1989: "International Approaches to Global Climate Change," Memorandum from C. Boyden Gray, Esq., Counsel to the President, to Office of the Assistant Attorney General, Richard B. Stewart, U.S. Department of Justice.

December 29, 1989: "In Reference to the Legal Measures Paper and the Economic Measures Paper from IPCC discussions on Oct. 2-6, 1989," Comments Submitted to IPCC Coordinators, Department of State, Bureau of Oceans and International Environmental and Scientific Affairs.

1990: Chandler, William U., "Carbon Emissions Control Strategies: Case Studies in International Cooperation," World Wildlife Fund and The Conservation Foundation.

1990: Brower, Michael, "Cool Energy: The Renewable Solution to Global Warming," Union of Concerned Scientists.

1990: "A World of Difference," Report of the Task Force on Global Climate Change, National Governors' Association.

1990: "Our Changing Planet: The FY 1991 U.S. Global Change Research Program (to Accompany the U.S. President's FY 1991 Budget)," Report by the Committee on Earth and Environmental Sciences, Department of Interior's Geological Survey.

1990: Stephen H. Schneider, "Global Warming: Are We Entering the Greenhouse Century?" Update, Vintage Books.

January 1990: "Global Warming: Administration Approach Cautious Pending Validation of Threat," Report to the Chairman, Subcommittee on Oversight and Investigations, Committee on Energy and Commerce, U.S. House of Representatives, Prepared by the U.S. General Accounting Office.

February 1990: "Economic Report of the President," Transmitted to the Congress together with the Annual Report of the Council of Economic Advisors, U.S. Government Printing Office.

February 3, 1990: "Materials for the Informal Seminar on U.S. Experience with 'Comprehensive' and 'Emissions Trading' Approaches to Environmental Policy," U.S. Department of State.

February 5, 1990: "Remarks by President Bush at the Intergovernmental Panel on Climate Change," Press Release, White House.

February 7, 1990: "Global Climate Change Briefing Book," Press Office, U.S. Department of Energy.

February 26, 1990: "Diplomacy for the Environment," Remarks by Secretary of State James A. Baker III Before the National Governor's Association, U.S. Department of State.

February 28, 1990: Kaufman, David Z., "The Greenhouse Effect: Available and Needed Laws and Treaties," George Mason University Law School.

March 1990: "Greenhouse Effect: Department of Energy's Programs and Activities Relevant to the Global Warming Phenomenon," Briefing Report to the Subcommittee on Environment, Energy and Natural Resources, Committee on Government Operations, House of Representatives, U.S. General Accounting Office.

April 11, 1990: "The Making of a Greenhouse Policy," Speech of D. Allan Bromley, Assistant to the President for Science and Technology and Director of Office of Science and Technology Policy, Executive Office of the President.

April 12, 1990: "R&D in the Federal Budget: 1991 and Beyond," Speech by D. Allan Bromley, Assistant to the President for Science and Technology and Director of Office of Science and Technology Policy, Executive Office of the President to the American Association for the Advancement of Science for a Science and Technology Policy Colloquium.

April 18, 1990: "Text of Remarks by the President at Closing Session of the White House Conference on Science and Economics Research Related to Global Change," Executive Office of the President.

May 1990: "Global Climate Change: An Energy Industry Perspective," United States Energy Association.

May 1, 1990: "Keeping America First: American Romanticism and the Global Economy," Press Release of Speech by Richard Darman, Director, Office of Management & Budget.

May 10-11, 1990: "Potential Effects of Climate Change on Electric Utilities," Presentation Papers, Project Advisory Committee Meeting, Electric Power Research Institute.

June 1990: "U.S. Initiatives to Reduce Greenhouse Gas Emissions," U.S. Department of Energy.

June 4, 1990: "Annual Environmental Quality Report—Excerpt on Global Environmental Issues," pp. 207-224, CEQ.

June 13, 1990: Warsh, David, "Game Theory Suggests Quick Action on Greenhouse Effect is Remote," *The Washington Post*.

July 1990: "Global Warming," Information and Position Package, National Association of Manufacturers.

August 1990: "Confronting Climate Change: Strategies for Energy Research and Development," Committee on Alternative Energy Research and Development Strategies, Energy Engineering Board, Commission on Engineering and Technical Systems, National Research Council, National Academy Press.

August 1990: Cristofaro, Alexander and Joel D. Scheraga, "Policy Implications of a Comprehensive Greenhouse Gas Budget," Office of Policy Analysis, Office of Policy, Planning and Evaluation, U.S. Environmental Protection Agency.

September 1990: Boyer, C.M. II, J.R. Kelafant, V.A. Kuuskraa, K.C. Manger, "Methane Emissions From Coal Mining: Issues and Opportunities for Reduction," Report for Dina Kruger, Air and Radiation, U.S. Environmental Protection Agency, ICF Resources Incorporated.

September 1990: "Replacing Gasoline: Alternative Fuels for Light-Duty Vehicles," Office of Technology Assessment.

September 5, 1990: "National Energy Policy Act of 1989," S. 324, offered by Sen. Wirth, referred to the Energy and Commerce Subcommittee on Science, Space and Technology, U.S. Senate.

September 5-7, 1990: Donaldson, D.M. and G.E. Betteridge, "Potential Impact of the Greenhouse Effect on Electricity Supply," Annual Symposium, The Uranium Institute (of London).

September 13, 1990: "Administration's Medium Term Energy Measures: Including Energy Efficiency; Fuel Switching, Alternative Fuels, and Oil Back-Out; Petroleum Supply Options," U.S. Department of Energy.

September 14, 1990: "The Enterprise for the Americas Initiative Act of 1990," White House Press Release with Accompanying Remarks by President Bush to Congress, Executive Office of the President.

September 26, 1990: "Aiming Before We Shoot: The Quiet Revolution in Environmental Policy," Address by William K. Reilly, Administrator, U.S. Environmental Protection Agency, to the National Press Club.

October 31, 1990: "A Comparison of Carbon Dioxide Emissions Attributable to New Natural Gas and All-Electric Homes," *Energy Analysis*, 1990-5, American Gas Association.

November 1990: Morandi, Larry, "Global Climate Change: State Policy Development Amid Scientific Uncertainty," National Conference of State Legislatures.

December 1990: MacKenzie, James and Michael P. Walsh, "Driving Forces: Motor Vehicle Trends and Their Implications for Global Warming, Energy Strategies, and Transportation Planning," World Resources Institute.

December 1990: "The Heat is On: America's CO₂ Polluters," Citizen's Fund.

December 1990: Lashof, Daniel A. and Dennis A. Tirpak, "Policy Options for Stabilizing Global Climate Change," Main Report to Congress, Office of Policy, Planning & Evaluation, U.S. Environmental Protection Agency.

December 20, 1990: Howes, John A., "Memo to U.S. Energy Executives: Don't Forget Global Warming," Vol. 126, No.13, pp. 12-13, *Public Utilities Fortnightly*.

December 28, 1990: "Near-Term Options for Reducing United States Carbon Dioxide Emissions," Report for Congress, Environment and Natural Resources Policy Division and Science Policy Research Division, Congressional Research Service.

1991: "America's Climate Change Strategy: An Action Agenda," Brochure, Executive Office of the President.

1991: Michaels, Patrick, Statement Before the California Energy Commission.

1991: "Our Changing Planet: The FY 1992 U.S. Global Change Research Program (to Accompany the U.S. President's FY 1992 Budget)," Report by the Committee on Earth and Environmental Sciences, Department of Interior's Geological Survey.

1991: "Policy Implications of Greenhouse Warming," Book, Synthesis Panel of National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, National Academy Press.

1991: "Policy Implications of Greenhouse Warming: Report of the Mitigation Panel," Prepublication Manuscript, Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, National Academy Press.

1991: "Policy Implications of Greenhouse Warming: Report of the Adaptation Panel," Prepublication Manuscript, Committee on Science, Engineering, and Public Policy, National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, National Academy Press.

1991: "Our Changing Planet: The FY 1992 U.S. Global Change Research Program," A Report by the Committee on Earth and Environmental Sciences, Office of Science and Technology Policy, Federal Coordinating Council for Science, Engineering & Technology, Executive Office of the President.

January 1991: Benedick, Richard E., Abram Chayes, Daniel A. Lashof, Jessica T. Mathews, William A. Nitze, Eliot L. Richardson, James K. Sebenius, Peter S. Thacher, and David A. Wirth, "Greenhouse Warming: Negotiating a Global Regime," World Resources Institute.

January 1991: "A Comprehensive Approach to Addressing Potential Climate Change," Interagency Task Force on Comprehensive and Incentives Approaches to Climate Change, Environmental & Natural Resources Division, U.S. Department of Justice.

January 1991: "Draft Resolution and Comments in the Senate on Global Climate Change," Introduced by Senator Mitchell, U.S. Senate.

February 1991: Oates, Wallace E. and Paul R. Portney, "Policies for the Regulation of Global Carbon Emissions," Resources for the Future.

February 1991: "Changing by Degrees: Steps to Reduce Greenhouse Gases," Executive Summary, Office of Technology Assessment.

February 1991: "Changing by Degrees: Steps to Reduce Greenhouse Gases," Main Report, Office of Technology Assessment.

February 1991: Jeffreys, Kent, "Why Worry about Global Warming?" National Center for Policy Analysis Report No. 96, National Center for Policy Analysis.

February 5, 1991: Menon, Pranhakar, Representative of India, "Statement at the First INC Session in Chantilly, Virginia."

February 1-14, 1991: "First Session of the Intergovernmental Negotiating Committee for a Framework Convention on Climate Change," Various Texts of Speeches and Letters, Intergovernmental Panel on Climate Change, World Meteorological Organization and United Nations Environment Programme.

February 21, 1991: "Global Climate Change: Effects and Impacts," Testimony of Stephen H. Schneider, National Center for Atmospheric Research, Before the Subcommittee on Health and the Environment, Committee on Energy and Commerce, U.S. House of Representatives.

February 21, 1991: "Bill to Amend the Internal Revenue Code of 1986 to Reduce Emissions of Carbon Dioxide by Imposing a Tax on Certain Fuels Based on Their Carbon Content," H.R. 1086, U.S. House of Representatives.

March 1991: Singer, S. Fred, "Global Warming: Do We Know Enough to Act?" Center for the Study of American Business, Washington University.

March 14, 1991: "Letter to Secretary of State James A. Baker III, U.S. Department of State," John Dingell, U.S. House of Representatives, Committee on Energy and Commerce.

April 1991: Mills, Mark, "Ecowatts, the Clean Switch Using Electricity to Save Energy and Cut Greenhouse Gases," Science Concepts Inc.

June 28, 1991: Justus, John R., Coordinator, "Global Climate Change," Issue Brief, Science Policy Research Division, Congressional Research Service.

July 9, 1991: "Methane Emissions From the Natural Gas Industry," Fact Sheet, Planning & Analysis Issues, American Gas Association.

August 27, 1991: "The President's Commission on Environmental Quality," Fact Sheet, Council on Environmental Quality, Executive Office of the President.

Summer 1991: Gray, C. Boyden and David B. Rivkin, "A 'No Regrets' Environmental Policy," *Foreign Policy*, No. 83, pp. 47-65, Carnegie Endowment for International Peace.

September 1991: Bradley, Richard A., Edward C. Watts, and Edward R. Williams, "Limiting Net Greenhouse Gas Emissions in the United States," Executive Summary, Report to the U.S. Congress, Prepared for the Office of Environmental Analysis, Deputy Under Secretary for

Policy, Planning and Analysis, U.S. Department of Energy, Battelle Pacific Northwest Laboratory.

September 1991: "Singer-Winston Survey of IPCC Reviewers."

September 1991: Reinstein, Robert, Deputy Assistant Secretary of State for the Environment, Health, and Natural Resources, and Chief U.S. INC Negotiator, Statement at the Third INC Framework Convention Session, Nairobi, Kenya.

October 1991: Zimmermeyer, Gunder, "Potentials for CO₂ Reduction as an Example for Prudent Policies to Protect the Climate," Presented to the International Committee on Coal Research in Washington, D.C.

October 1991: "America's Energy Choices: Investing in a Strong Economy and a Clean Environment," Executive Summary, Alliance to Save Energy, American Council for an Energy-Efficient Economy, Natural Resources Defense Council, Union of Concerned Scientists.

October 29, 1991: "Draft Bill in the House on Greenhouse Warming," Introduced by Representative Phil Sharp, U.S. House of Representatives.

November 1991: Gray, John E., Robert W. Fri, Toyooki Ikuta, Donald L. Guertin, and Takao Tomitate, "Global Climate Change: U.S./Japan Cooperative Leadership for Environmental Protection," Joint Report, The Atlantic Council of the United States.

November 1991: "Assessment of Greenhouse Gas Emissions Policies on the Electric Utility Industry: Costs, Impacts, and Opportunities," Draft Final Report, ICF Resources, Inc. for the Edison Electric Institute.

November 19, 1991: Dr. Sherwood Idso, Testimony Before the California Energy Commission.

November 22, 1991: "Sustainable Energy Transition Act of 1991, S. 2020," U.S. Senate.

December 1991: "Eurelectric's Position on the Community Strategy to Limit Carbon Dioxide Emissions and to Improve Energy Efficiency," Eurelectric Committee, European Committee of the Electricity Supply Industry.

Technology Cooperation

Date Unknown: "Greenhouse: New Technologies, Business Opportunities and Strategies for Reducing U.S. Greenhouse Gas Emissions," Conference sponsored by the U.S. Environmental Protection Agency, et al.

December 1989: "Energy Technology for Developing Countries: Issues for the U.S. National Energy Strategy," Prepared for the U.S. Department of Energy by Lawrence Berkeley Laboratory, Argonne National Laboratory, Oak Ridge National Laboratory, Sandia National Laboratory, Solar Energy Research Institute, Los Alamos National Laboratory, and Pacific Northwest Laboratory, Lawrence Berkeley Laboratory.

January 1990: "The Technology Transfer Process: Background for the U.S. National Energy Strategy," Prepared for the U.S. Department of Energy, by Pacific Northwest Laboratory, Oak Ridge National Laboratory and Solar Energy Research Institute.

April 1990: "Transforming Technology: An Agenda for Environmentally Sustainable Growth in the 21st Century, World Resources Institute.

April 23, 1990: "Electric Power Technology," National Association of Regulatory Utility Commissioners' Staff Subcommittee on Technology for the Association's Committee on Finance and Technology.

May 1990: "Interim Report of the International Environmental Technology Transfer Advisory Board," Prepared for the U.S. Environmental Protection Agency by the International Environmental Technology Transfer Board.

June 19-21, 1990: "Final Program: Greenhouse," Conference Proceedings, Sponsored by U.S. Environmental Protection Agency, University of Maryland Center for Global Change, Harvard University Kennedy School Energy and Environmental Policy Center, Princeton University Center for Energy and Environmental Studies, and the National Institute for Emerging Technology.

December 1990: "Final Report of the International Environmental Technology Transfer Advisory Board," Prepared for the U.S. Environmental Protection Agency by the International Environmental Technology Transfer Board.

December 6, 1990: "Fifth and Final Full Meeting of the International Environmental Technology Transfer Advisory Board," Meeting Proceedings, International Environmental Technology Transfer Board.

January 1991: "Energy in Developing Countries," Office of Technology Assessment, U.S. Congress.

February 1991: "Clean Coal Technology Demonstration Program Update 1990," U.S. Department of Energy.

April 1991: Heaton, George, Robert Repetto, and Rodney Sobin, "Transforming Technology: An Agenda for Environmentally Sustainable Growth in the 21st Century," Partial Support from the National Science Foundation, World Resources Institute.

April 1991: "Fossil Energy: From Laboratory to Marketplace," Office of Fossil Energy, U.S. Department of Energy.

April 1991: "The Environmental Technology Export Council: A Business/Government Partnership," Draft Concept Paper, Environmental Technology Export Council.

January 7, 1992: "U.S.-Asian Partnership Creating 'Fertile' Environmental Markets," *World Environment Report*.