National Commission on Air Quality
Carbon Dioxide Workshop
Don Cesar Hotel, St. Petersburg, Florida
October 29-31, 1980

Proposed Agenda

WEDNESDAY, OCTOBER 29

6:30 p.m.	Reception, (South Terrace, 5th Floor)
7:30 p.m.	Dinner
9:00 p.m.	Introductory Remarks

THURSDAY, OCTOBER 30

9:00 a.m.	Welcome: NCAQ Commissioner Jeanne Malchon, County Commissioner, Pinellas County, Florida (Grenada Hall-West, Ground Floor)
9:10 a.m.	Opening Remarks: Thomas Jorling, Workshop Moderator
9:30 a.m.	CO_2 and Energy Policy: Ruth Clusen, Assistant Secretary for Environment, Department of Energy
10:00 a.m.	Begin Workshop Discussion: Scientific Uncertainties and Policy Development
12:30 p.m.	Lunch
1:30 p.m.	Resume Workshop Discussion: Need for and Timing of Policy Development
5:00 p.m.	Adjourn
8:00 p.m.	Tentative evening session

FRIDAY, OCTOBER 31

8:30 a.m.	Review of draft conclusions and recommendations
9:00 a.m.	Discussion of draft conclusions and recommendations
12:00 p.m.	Working Lunch
1:00 p.m.	Adjourn

National Commission on Air Quality

Background and Purpose Statement

for the

CARBON DIOXIDE WORKSHOP

ST. PETERSBURG, FLORIDA

OCTOBER 30-31, 1980

499 South Capitol St., SW, Washington, DC 20003 (202) 245-2405

Introduction

The National Commission on Air Quality was established by the Clean Air Act Amendments of 1977 (P.L. 95-95) to evaluate the Nation's air quality programs and to make recommendations to Congress for improving them. One of the Commission's mandates is to study and evaluate options for controlling air pollutants which are currently not regulated, but which may endanger public health or welfare, either now or in the future. Included among the public welfare impacts which are to be considered are effects on weather and climate.

In the past five years, some members of the scientific community have voiced concern over the potential climatic effects of anthropogenic emissions of carbon dioxide (CO_2). For example, in a 1977 report sponsored by the National Academy of Sciences (NAS), the combustion of fossil fuels was linked to increased atmospheric CO_2 levels and to subsequent global warming. In view of such concerns, the Commission is sponsoring a workshop to assess the need for developing and implementing public policy responses to CO_2-induced climate change*.

To date, most of the reports or debates on the CO_2-climate issue have focused on the scientific and technical uncertainties surrounding the issue and on establishing research plans to resolve these uncertainties. Some of the major milestones in this process have been:

- The report "Energy and Climate" sponsored by NAS mentioned above (1977)
- The ERDA-sponsored "Workshop on the Global Effects of Carbon Dioxide from Fossil Fuels" (March, 1977)
- Passage of the National Climate Program Act (P.L. 95-367), which establishes an interagency research program on natural and man-induced climate change (September, 1978)
- The DOE-sponsored "Workshop on Environmental and Societal Consequences of a Possible CO_2-Induced Climate Change" (April, 1979)
- The report of an NAS ad hoc study group on CO_2 and climate entitled "Carbon Dioxide and Climate: A Scientific Assessment" (July, 1979)
- The development of a comprehensive CO_2 research plan under the DOE Carbon Dioxide Effects Research and Assessment Program. Part I of this plan deals with the global carbon cycle and CO_2-induced climate effects and was published this August following extensive review by the scientific community. The second part of the plan deals with environmental and societal consequences of CO_2-induced climate change and is currently in preparation.
- Passage of the Energy Security Act (P.L. 96-294). Title VII of the Act directs the Office of Science and Technology Policy (OSTP) to commission an NAS study of the projected impact of fossil fuel combustion, coal conversion and other activities on atmospheric levels of CO_2, and of the subsequent effects of this impact.

---

*Throughout this discussion the term "CO_2-induced climate change" will be used to indicate change traceable to human activities, as opposed to natural fluctuations in atmospheric CO_2 levels.

- A number of international scientific activities, including the development of a coordinated plan of action for international research on CO_2 by the United Nations Environment Programme (UNEP), the World Meteorological Organization (WMO), and the International Council of Scientific Unions (ICSU).

By comparison with these scientific efforts, lesser emphasis has been placed on considering the policy implications of CO_2-induced climate change, and, in particular, on evaluating alternative policy options. Two major reports which have addressed these issues are:

- A report to the Council on Environment Quality (CEQ) entitled "The Carbon Dioxide Problem: Implications for Policy in the Management of Energy and Other Resources" (July, 1979)

- A report commissioned by OSTP from the NAS ad hoc Study Panel on Economic and Social Aspects of Carbon Dioxide Increase (April 18, 1980).

While both of these policy-oriented reports identified a number of interesting policy implications of increased CO_2 levels, they differed substantially in their conclusions. For example, the report to CEQ recommended that rather than waiting for proof of CO_2-induced climate change, policy measures to control emissions of CO_2 should be developed now. The report to OSTP, on the other hand, concluded that while there are currently too many scientific uncertainties about the CO_2-climate relationship to explore questions of policy, "we believe we can learn faster than the problem can develop". Furthermore, both study groups were composed primarily of scientists and academics, rather than actual policy makers.

Purpose

In view of the situation described above, and of the Commission's mandate, the primary purpose of this workshop is to bring together leading scientists and policy-makers to assess whether, and if so, when, public policy measures should be adopted to either prevent or adapt to CO_2-induced changes in global climate. To the extent that time permits, opportunity will also be provided to discuss specific types of policy measures which might be considered. Specifically, the workshop discussions will focus on two major policy-related questions:

1. Are the potential consequences of increased atmospheric CO_2 levels significant enough to warrant development of public policy responses either now or in the future?

2. What is the nature of the relationship between scientific CO_2-climate endeavor and the development of public policy. For example, what are the possible trade-offs between taking certain actions now, based on very limited information, versus delaying a decade or more in hopes of having better information on which to act?

Scientific Issues

Traditionally, carbon dioxide has not been treated as an air pollutant. However, the global atmospheric concentration of CO_2 has been observed to increase steadily over the last 20 years, and is believed to have been rising since the mid-19th century. These increases have been attributed primarily to the combustion of fossil fuels, and to a lesser extent, to other human activities such as deforestation. For example, it has been predicted that if the use of fossil fuels continues to grow at rates seen in the last few years, global atmospheric levels of CO_2 will double by the middle of the 21st century.

A global increase in the atmospheric concentration of CO_2 is of concern because it may lead to a warming of the lower atmosphere, primarily by increasing the atmosphere's absorption of infrared radiation. Recently, an ad hoc group of the NAS Climate Research Board concluded that if atmospheric CO_2 levels continue to increase, climate changes are expected to occur and to be significant. For example, the report stated that a global increase of $3°C \pm 1.5°C$ in annual average temperature will probably result from a doubling of the global CO_2 concentration. However, the climatic changes would occur with uneven geographic distribution. For example, greater warming is expected to occur at the higher latitudes.

The direct results of such global warming could include changes in agriculture (due to changes in growing seasons, the distribution and amount of precipitation, etc.), changes in the distribution, composition, and productivity of natural ecosystems, and changes in oceanic circulation. In addition, it is speculated that portions of the polar ice sheets could collapse, leading to an increase in sea level. Of course, changes in climate and their attendant consequences have occurred naturally since the earth was formed. Climate changes resulting from man-induced increases in atmospheric CO_2 levels are of special concern, however, because they can occur over decades, rather than over millenia, and because the increases are expected to persist for hundreds of years.

Currently, there are significant scientific uncertainties concerning the relationship between human activities, atmospheric levels of carbon dioxide, climate, and the global environment. As discussed earlier, these uncertainties have been identified and are being addressed through national and international research activities. Although this workshop will not explore these uncertainties intensively, it cannot proceed without identifying the key scientific issues which will help shape the policy discussion. Some of the major uncertainties include:

1. The rate at which atmospheric CO_2 levels might rise cannot be predicted accurately because of lack of specific knowledge about:

- the main sources of CO_2 and their potential contribution to increased atmospheric CO_2 levels;

- the main non-atmospheric sinks of CO_2 (oceans, biosphere, and sediments) and the extent and speed with which they will store increases in CO_2; and

- the relative importance of different sources and/or sinks of CO_2 (for example, fossil fuel combustion vs. deforestation).

2. The expected magnitude, timing, distribution and persistence of climate changes associated with specific increases in atmospheric CO_2 concentrations are not precisely known. For example, there is disagreement about whether CO_2-related changes in climate should already be detectable

3. The environmental consequences of global warming and their expected magnitude, timing, and geographic distribution are not adequately understood.

4. The likely social, economic, and political consequences of climate change are difficult to predict because of the lack of information about:

- The potential costs and benefits to society. (For example, are the costs likely to outweigh the benefits, or vice-versa?); and

- How these costs and benefits might be distributed geographically or socio-economically (e.g., among developed vs. developing nations, northern hemisphere vs. southern hemisphere, etc.).

Policy-Related Issues

As stated above, the purpose of the workshop is to assess whether, and if so, when policies should be developed and adopted in response to the potential for CO_2-induced climate change. The following list of key policy-related issues is provided to stimulate and guide the workshop participants' discussion of these issues. However, it is not intended to be exhaustive or to limit the discussion to these issues.

1. What, if any, are the major uncertainties that must be resolved before policy choices are made?

- Are these uncertainties likely to be resolved in the next ten years? Twenty years? For example, how likely is it that current research programs will provide conclusive evidence of CO_2-induced climate change in this ten to twenty year time frame?

- Are these uncertainties so significant as to preclude the development of policy options at present?

- Does scientific evidence available today warrant development of any policies?

2. How much lead time is required to develop and implement policy measures in response to potential CO_2-induced climate change?

- What effect might delay have in terms of precluding, limiting, or reducing the feasibility of various policy options? In expanding them?

- If preventive actions are required, when should they be taken? How long might it take to formulate and implement them? How long before results will occur?

- How long might it take to develop and adopt coordinated international policies to prevent CO_2-induced climate change? To adapt to such change?

3. What changes in energy, air quality, land use, and foreign policies might be considered to prevent CO_2-induced climate changes?

- How effective might they be?

- Which actions can be taken unilaterally? Which require the cooperation of other nations?

- What are the relative advantages and disadvantages of these actions? Which nations and/or sectors of the public will experience these advantages and disadvantages?

- How much and what types of information are required to justify taking preventive actions? When is this information expected to be available?

- How likely is it that preventive measures will be adopted soon? In a decade?

4. What actions might be taken to adapt to the consequences of CO_2-induced climate change?

- Which nations will be most able to take these actions?

- What compensatory measures might be considered (e.g., increased food aid to countries that lose agricultural productivity)?

- What are the socio-economic and other tradeoffs between preventive and adaptive actions?

5. What international mechanisms are available for either preventing or adapting to CO_2-induced changes in climate?

- What precedents exist for international action? Have such actions been successful?

- What are the chances of success in seeking international cooperation on measures to prevent CO_2-induced climate change? On adaptive/compensatory measures?

NATIONAL RESEARCH COUNCIL
ASSEMBLY OF MATHEMATICAL AND PHYSICAL SCIENCES

2101 Constitution Avenue Washington, D. C. 20418

CLIMATE RESEARCH BOARD

April 18, 1980

Dr. Philip Handler
President
National Academy of Sciences
2101 Constitution Avenue
Washington, D.C. 20418

Dear Dr. Handler:

In a letter dated January 2, 1980, Dr. Press requested that the Academy assess for him, as promptly as possible, the likely foreseeable social and economic consequences of an increasing concentration of atmospheric carbon dioxide. He also requested a judgment on any implications for policy.

We were appointed members of a panel under the Climate Research Board and asked to provide such an assessment. It was understood that we would have to base our conclusions on what is currently understood about the likely increases in atmospheric carbon dioxide and the relation of carbon dioxide to climate. We took as a basis for our discussions the scientific consensus on the climatic effects of increased atmospheric carbon dioxide as presented, for example, in the 1977 Geophysics Study Committee report, Energy and Climate, and the 1979 report of an ad hoc Climate Research Board panel, Carbon Dioxide and Climate: A Scientific Assessment. We were aware that questions had recently been raised about the magnitude of the projected climate changes.* We acknowledge that the range of uncertainty in estimates of future influences on climate is indeed wide. However, we have accepted the judgments of qualified members of the panel and other experts we consulted that these recent estimates of extremely small effects are based on incomplete assessments that unrealistically omit important feedback processes. Starting from these premises, we undertook to use our best judgment about the social and economic context on which any climate changes would impinge during a period that is half a century or more in the future. We did not undertake new research. Most of what we report must therefore be recognized as a collective judgment rather than as a scientific finding.

Society has developed in a relatively stable global pattern of climate. We face the possibility of a markedly different climate in 50 years in consequence of the continuing buildup of atmospheric carbon dioxide. Furthermore:

> <u>This issue is inherently and inescapably international in character</u>. The phenomenon is global: different countries will be affected differently, but none will be immune. No single nation can forestall undesirable consequences by its own actions alone.
>
> <u>It is linked to other intensely controversial problems</u>: energy, environment, population, economic growth, north-south conflict, unequal distribution of resources and wealth, pollution across boundaries, migration.
>
> <u>Its implications are inherently divisive</u>. Climate change will benefit some and harm others. Advanced countries will be major carbon users but may suffer the least. Adverse changes in climate are usually felt in the increasing frequency and severity of familiar extremes, such as drought; whether carbon dioxide is the cause and who is to blame will be inherently difficult questions to resolve.

---

*R. E. Newell and T. G. Dopplick (1979). Questions concerning the possible influence of anthropogenic carbon dioxide on atmospheric temperature. <u>J. Appl. Meteorol. 18</u>, 822-825.
S. B. Idso (1980). The climatological significance of a doubling of earth's atmospheric carbon dioxide concentration. <u>Science 207</u>, 1462-1463.

Critical Uncertainties

The credible range of effects is extremely broad. By the middle of the next century, we may have a climate almost as different from today's as today's is from the peak of the last major glaciation. At the other extreme, we may only experience noticeable but not necessarily unfavorable effects around mid-century or later.

Uncertainties lie in four principal areas:

1. Sources of carbon dioxide. The magnitude of future injections of carbon dioxide will depend on how the world's population obtains its energy and, to some extent, uses its land. Projections based on today's technology may prove irrelevant if new energy sources and ways of life compete successfully against coal burning.

2. Airborne concentrations. Carbon dioxide in the atmosphere is part of a complex carbon cycle. The nonatmospheric reservoirs of carbon are in the aggregate much larger than the atmospheric. Projections of future airborne concentrations depend on the uncertain partitioning of carbon dioxide among the reservoirs.

3. Climate response. Increases in atmospheric concentrations affect the energy exchange of the climate system. Changes in climate must be estimated from models of the entire system--the atmosphere, oceans, ice and snow, and land surface. There is uncertainty about the magnitude, timing, and global distribution of climate changes even for a given change in carbon dioxide concentration.

4. Socioeconomic impact. Even in agriculture, which will be one of the most affected activities, there would be both positive effects (e.g., of enhanced carbon dioxide on photosynthesis) and negative effects (e.g., of reduced rainfall in some regions), and there are uncertainties about genetic adaptation of crops, irrigation techniques, and dietary developments. Other impacts are similarly uncertain if only because they are decades into the future.

There is assuredly enough economically accessible fossil fuel--primarily coal--to inject into the atmosphere several times as much carbon dioxide as it now holds. That is not in dispute. But it is not certain how much will be burned or how rapidly. Once established, elevated carbon dioxide levels would then almost certainly persist for many centuries.

In addition to problems of adjusting to a gradually changing climate, there may be thresholds or discontinuities. At some point within the range of carbon dioxide increases that known reserves of fuels could produce, the floating Arctic Ocean sea ice would disappear in summer, radically altering the meteorology of the northern hemisphere, with consequences that are not now predictable. Another concern is the West Antarctic Ice Sheet. A warmer climate with warmer oceans might cause it to disintegrate over a period of a decade to centuries, raising sea levels by about 15 to 20 feet, enough to jeopardize many of the world's cities. We have not examined any of the protective measures--whatever they may be--that might be considered, nor have we assessed the plausibility of the contingency itself.

It is also possible that the required rate of adjustment to changes in climate will be very great. Fossil-fuel consumption may indeed increase steadily; increments of carbon dioxide may become harder to absorb in the biosphere and ocean, an increasing proportion remaining airborne; whatever the climatic response, the pace of adaptation required could well accelerate.

There is a further point that is not adequately suggested by the term "climate change." Food production is not just a function of average rainfall or temperature; changes in the variability of climate would affect food production.

Potential Impacts of Climate Change

Economic impacts of changing climate would certainly be felt in agriculture. Changes in precipitation would be most significant and most conspicuous, but changes in temperature and growing seasons, sunlight, and the frequency of storms would also be important. Shifts in climate zones and in the loci of agricultural activity may create new combinations of soil and climate to which existing crops and farming practices would be imperfectly adapted. Marine resources, including fisheries, are also sensitive to changes in ocean chemistry and climate. The increased concentration of carbon dioxide should, up to a point, directly increase the rate of photosynthesis and improve water utilization and nitrogen fixation by plants in agriculture. (Artificially enhanced carbon dioxide is now used to increase productivity in commercial greenhouses.) The net effect on aggregate food production, which depends on many complex factors, is uncertain and would depend greatly on the rate of climate change and the ability of different peoples to adapt; the most serious consequences are likely to be in the distribution of gains and losses among areas of the world.

What is certain is that established patterns of agriculture would have to change, and in some areas might be disrupted.

Other direct effects of climate change, e.g., on energy demand, navigation, tourism, appear of lesser significance than food production, but we cannot say they will be negligible. Second-order effects may prove important, e.g., conversion of stable permafrost to impassable bog. Our welfare is linked to the stable functioning of many ecosystems; disturbances can have unexpected consequences. For example, outbreaks of agricultural pests or certain human diseases may be triggered by changes in climatic conditions.

It is worth remarking that the major foreseeable effects of carbon dioxide will be a different distribution of climate, not the creation of entirely new kinds of climate. The present climates of the globe span an exceedingly wide range from the Arctic to the desert. Indeed, the migration to and throughout the new world subjected large numbers of people--together with their livestock, food crops, and culture--to drastically changed climate.

The overall economic cost (or benefit) of the sort of climate change associated with a doubling of carbon dioxide may be no more than a few percent of world gross national product (GNP). But the seriousness cannot be assessed in GNP alone. The geographical pattern of climate change may produce a drastically unequal distribution of impacts. For example, northern countries might benefit, despite disruption, from a general warming; on the other hand, an expansion of subtropical arid regions would affect primarily the poorer countries. Developed countries with advanced and diverse agriculture, and in which agriculture accounts for a relatively small proportion of the GNP, would probably be better able to adapt to change than would less-developed ones, which are strongly dependent on agriculture. It seems that climate change might well tend to make the already poor still poorer and increase the differences between north and south, rich and poor, developed and developing. We emphasize again the uncertainties: substantial changes could occur within forty or fifty years and be accelerating in mid-century, or could be delayed many decades beyond.

Responses to Change in Climate

Although climate change would certainly affect agriculture, technologically advanced agriculture has proved to be quite resilient under climate change. Modest changes have been accommodated in this century, and the ability of crops to prosper under a range of climatic conditions has been greatly extended through genetic improvements. Further advances may aid agricultural adaptation to climate changes.

Changes in availability of water are the single most significant consequence of climate change that we foresee through the next century. Present use of water for agriculture is highly inefficient in most countries. Improvements in irrigation and water delivery could increase production even in the face of declining precipitation. The obstacles are as much legal and institutional as technological. Changes in water supply also affect the availability of water of adequate quality for industrial and human consumption. However, large-scale, long-distance transfers of water currently seem unlikely; most opportunities for large-scale, gravity-fed transfer have already been exploited, and rising energy costs will discourage pumped long-range water transfers. For the most part, regional water needs will have to be met by regional resources. While modest precipitation decreases in areas well supplied at present could be accommodated, similar decreases in some currently marginal semiarid regions and increases in the frequency of drought could have serious impacts.

Migration has historically been the principal means of adapting to climate change. But today's political barriers hamper migration, and national boundaries are not likely to be more open in the future. If migration out of climatically impoverished areas is not feasible, transfer payments and other technology and capital to aid local adaptation to climatic change may have to be considered for such areas.

Preventing or delaying the increase in carbon dioxide would have to be done mainly by restricting the use of fossil fuels, although management of land and forests could also contribute. Only coal is likely to be economically available in the quantities required to double or more than double the airborne carbon dioxide. Known coal reserves are mainly concentrated in a few major countries: the United States, the Soviet Union, and China together hold most of the known reserves. Emissions can therefore be controlled only if these countries, which agree on little at present, agree in the future not to exploit for their own use or make available to other countries without restriction this part of their natural wealth, or if most of the consuming countries can agree to restrict their imports. Moreover, in our judgment the Soviet Union and the United States--because of their geographical extent and general economic development--are likely to be among the nations most able to adapt to, or even benefit from, climate change.

In the absence of attractive alternative energy sources, voluntary control of coal use and coal exportation by any of the three major coal-holding nations would be unlikely unless it were clear that the unfavorable consequences of climate change significantly outweighed the benefits of coal exploitation. Similarly, self-imposed restrictions on energy demand by countries without coal would hardly find ready acceptance unless this self-denial was obviously in their own best interests; for each nation individually it would not be. Technological aid to fuel-poor developing nations for development of alternative energy sources is therefore an attractive policy to the extent that it can reduce their fossil-fuel needs. In summary, restraint on fossil fuel will require global cooperation, reductions in energy demand, and the widespread introduction of alternative energy sources.

Policy Choices under Uncertainty

Carbon dioxide and climate are not the only uncertainties in our future. In the next half century, world population will probably double and global GNP will, one hopes, increase by a larger multiple. Comparable changes took place between the early years of this century and today. If we had attempted in 1900 to predict the world of 1980, we might well not have foreseen air travel, nuclear energy, space exploration, recombinant DNA, and digital computers. Future technology may overshadow, in both benefits and damages and their differential impacts among peoples, the effects of carbon dioxide. Significant progress in weather modification, water management, development of alternative energy sources, or agricultural technology would change our assessment of the problem.

Some implications of increased concentration of carbon dioxide, however, are clear:

1. Our immediate problem is uncertainty itself. We must reduce that uncertainty through research. We discuss this further below.

2. Research notwithstanding, uncertainty will persist. Even as the dimensions of the problem become clearer, it may be necessary to base preventive and adaptive policies on uncertain predictions.

3. We must recognize now that increases in energy consumption using fossil fuels will have increasingly undesirable climatic effects.

4. We and the main energy-consuming countries must keep open a number of options for energy and not become committed to an extended period of unrestricted fossil-fuel use.

5. Agriculture would be most certainly affected, especially through changes in the availability of water. We should enhance the resilience of agriculture to changing climate, through research in the adaptability and diversity of species, irrigation techniques, and water conservation and transport.

6. Climate changes will produce increased pressures in some parts of the world for migration within and across national boundaries, a potential source of conflict.

7. Climate changes, and measures to prevent them as well, would constitute for some countries an adverse redistribution of resources and could generate demands for compensation.

8. Current capabilities give no grounds for hoping that controlled weather modification could compensate for global changes in climate. Breakthroughs in climate control could alter this assessment, but there is no assurance that any breakthroughs would be less divisive in their effects than the climate changes that would occur in their absence.

9. Slowing the growth in fossil-fuel combustion will make adaptation to climate change easier and may permit more absorption of carbon into nonatmospheric sinks. It will also permit conversion to alternative energy sources at a lower cumulative carbon dioxide concentration, and it is likely that the sooner we begin the transition from fossil fuels the easier the transition will be.

10. Carbon dioxide is but one of a class of "global commons" issues that includes chlorofluoromethanes and acid rain. The precedents we set in dealing internationally with any of these issues, in regulation or research, will influence how we deal with carbon dioxide.

11. There is an intricate linkage of carbon dioxide with other intensely divisive issues: nuclear power and preservation of the environment, markets and central economic planning,

"north versus south" and the gap between developed and developing nations, and even OPEC and the demand for oil.

Implications for Research

Present knowledge is an insufficient basis for international action to prevent climate changes or to adapt to them. Two kinds of knowledge and capability should be improved. First, we need to reduce the uncertainties about future carbon dioxide injections, their climatic effects, and the social and economic implications. It will be important to verify observationally the model predictions of climate change as soon as possible by carefully designed monitoring programs. Continued research in ocean chemistry and dynamics, the biogeochemical cycling of carbon, the myriad processes that influence climate, and the building and validation of climate models will be necessary. We must also learn much more about the impacts of a climate change on human activities, especially agriculture and its complex interaction with society. This first stream of research to clarify the links between our actions and their consequences will enable us to measure the problem and to assess its importance with respect to other societal issues. Second, we need to learn more about how we might adapt to climate change or prevent it. Our discussion above has indicated some of the knowledge needed in agricultural technology, energy production, and management of forests and soils.

Recommendations for Near-Term U.S. Policy

Better understanding will emerge slowly, but knowledge can probably be made to grow faster than the problem. The information needed to choose a balance of adaptation and prevention should be of much better quality in five or ten years. But this information will be of little value if options are not available. We must ensure that options for adaptation and prevention remain open.

The challenge is to progress toward an international consensus on the carbon dioxide issue while minimizing its factious involvement with other issues and its own divisive aspects. The carbon dioxide issue should appear on the international agenda in a context that will maximize cooperation and consensus-building and minimize political manipulation, controversy, and division.

Our understanding of the issue has been developed in the context of research on climate, its changes, and their interaction with mankind. A World Climate Program, led by the World Meteorological Organization, has been established to improve the world's ability to cope with contemporary climate, natural climate fluctuations, and man-made climate changes. Most of the research necessary to improve our understanding is at least conceptually provided for in this program. Moreover, as part of this program, several international organizations are organizing a sequence of activities to develop a cross-cutting "Plan of Action" specifically relating to the assessment of the carbon dioxide issue. Thus, a relatively nonpolitical and broadly supported framework for international study exists. The effectiveness of these activities is as yet unproven.

In view of the uncertainties, controversies, and complex linkages surrounding the carbon dioxide issue, and the possibility that some of the greatest uncertainties will be reduced within the decade, it seems to most of us that the near-term emphasis should be on research, with as low a political profile as possible. We should emphasize that this is both a technical and a political judgment. Another point of view represented on the panel is that further research will not fundamentally change our perception of the issue; in this view, the need for preventive measures is already apparent and urgent.

Most of the things one would want to do now to prepare for dealing with the carbon dioxide problem are things one would want to do for other reasons. Overdependence on a single energy source has already proven to be unwise; development of alternative energy sources is clearly necessary. Energy production has many troublesome environmental effects, including carbon dioxide; we should study how to alleviate them. Climate variability already causes problems; we want in any event to learn more about climate and its interaction with society. The past teaches us that significant natural climate changes are likely; we should consider how to cope with their impacts, whether induced by nature or man. The carbon dioxide problem increases the urgency of this research; it does not fundamentally change its nature.

The one exception is the novel possibility of elevated ocean levels due to disintegration of the West Antarctic ice sheet. Research bearing directly on the likelihood and timing of such a development is needed, and an exploration of protective and adaptive measures should be initiated. (The problem of "rising" sea levels due to land subsidence and the silting of river bottoms is itself not new, and the first stages should be to assemble what is already known, both in the United States and abroad.)

In all of this, we need to keep in mind that this earth is the only planet we have on which to live. We humans have made major changes in our environment without yet destroying its ability to support us. This may demonstrate great resilience in the earth's life-support systems; but we may just have been lucky. As we grow in numbers and power, we will make ever greater demands on our planet, and there is no guarantee that we will not get into trouble in ways that we have not yet discovered or even imagined.

Conclusion

To sum up, carbon dioxide will pose exceedingly difficult and divisive policy questions for all the world's nations individually and collectively. We do not know enough to address most of these questions right now. We believe we can learn faster than the problem can develop. This learning can be done while we address with increasing urgency the problems of living with changing resources of energy, land, and climate.

Sincerely,

Ad Hoc Study Panel on Economic and Social Aspects of Carbon Dioxide Increase
Thomas C. Schelling, Chairman
McGeorge Bundy
Abram J. Chayes
Charles W. Howe
Bruce K. MacLaury
William Nierenberg
William Nordhaus
Herman Pollack
Roger R. Revelle
Joseph Smagorinsky
Robert M. White
Sylvan Wittwer
George Woodwell

The Carbon Dioxide Problem: Implications for Policy in the Management of Energy and Other Resources

A Report to the Council on Environmental Quality

by

George M. Woodwell
Gordon J. MacDonald
Roger Revelle
C. David Keeling

July 1979

I. The CO_2 Problem

Man is setting in motion a series of events that seem certain to cause a significant warming of world climates over the next decades unless mitigating steps are taken immediately. The cause is the accumulation of CO_2 and other heat-absorbing gases in the atmosphere. The result is expected to be a differential warming of the atmosphere near the earth's surface, a warming that will probably be conspicuous within the next twenty years. If the trend is allowed to continue, climatic zones will shift, and agriculture will be displaced. Such a series of changes would have far reaching implications for human welfare in an ever more crowded world, would threaten the stability of food supplies, and would present a further set of intractable problems to organized societies. The best estimates suggest that there would be the least change in temperature in the tropics but polar regions would grow substantially warmer. With sufficient high latitude warming the ice cap in the western part of the Antarctic Continent could disappear in a period as short as two centuries, causing a 20-foot rise in sea level with resulting inundation of low-lying coastal zones. Enlightened policies in the management of fossil fuels and forests can delay or avoid these changes, but the time for implementing the policies is fast passing.

The carbon dioxide content of the atmosphere is increasing at an annual rate that is now about 1.5 ppm in a background of about 333 ppm. The increase since 1860 is at least 40 ppm, possibly as much as 70 ppm. Precise data on the increase are available since 1958 when monitoring stations were established on Mauna Loa in the Hawaiian Islands, at the South Pole, and intermittent sampling was intensified elsewhere. The data show that the rate of increase is accelerating as the world use of fossil fuels increases. The rates of both are between 3 and 4% annually. This rate means that in each period of between 18 and 23 years approximately twice as much CO_2 accumulates in the atmosphere as accumulated in the previous period.

The problem is that CO_2, in contrast to the major atmospheric components O_2 and N_2, absorbs infra-red radiation, which is the principal outgoing radiation from the earth's surface to outer space. Over any extended period the infra-red radiation emanating from the top of the atmosphere must balance the solar radiation absorbed by the atmosphere, the oceans, and the earth's surface. The increase in the CO_2 in the atmosphere can thus be expected to result in a rise in the surface temperature until the outgoing infra-red radiation comes into balance with the absorbed solar radiation. The extent of the heating that will result depends on many factors and is difficult to predict, but there is reasonable agreement that it will occur and will be conspicuous before the end of this century. The changes in climate that will follow such an increase in temperature are also elusive. The experience from models of world climate is that the warming may be as much as an average of 2-3°C for a doubling of the CO_2-content of the atmosphere and that the warming will be greater by a factor of three or four near the poles and less in the tropics.

There appear to be very few clear advantages for man in such short-term alterations in climate. The displacement of agriculture in a world constantly threatened by hunger would alone constitute an extremely serious international disruption within the lifetimes of those now living. The warming of the Antarctic could, according to some estimates, result in the disappearance of the West Antarctic ice sheet in a period as short as 200 years. Such a process could be started by an increase in summer temperature in the Antarctic ocean surface waters of 5°C. Such an increase could occur in 50-75 years if current trends continue. A complete disappearance of the West Antarctic ice sheet would raise sea level by as much as 20 feet worldwide.

By itself the increase in atmospheric CO_2 would probably be beneficial for agriculture because the added CO_2 will act as a fertilizer for crop plants. But there is little basis for hope that a decades-long warming of the earth will result in benefit for man. Certain areas now suitable for agriculture will become arid, others, now limited by short season, will become arable.

The cause of the current increase in CO_2 in air is the oxidation of carbon compounds worldwide. Fossil fuels are one, probably the major, source. The harvest of forests and the decay of soil humus are thought by some to be an equally important contemporary source, although its importance will decline with time. The important fact, however, is that the atmosphere is a comparatively small reservoir. It contains about 700×10^{15} g of C. The biota is variously estimated as containing about 800×10^{15} g; the humus, $1000\text{-}3000 \times 10^{15}$ g; and the oceanic water nearly $40{,}000 \times 10^{15}$ g. Reserves of fossil fuels contain at least 5000×10^{15} g. The current use of fossil fuels is releasing $5\text{-}6 \times 10^{15}$ g C annually and the biota and humus are probably contributing an amount of similar order of magnitude. The combustion of fossil fuels has the potential for a greatly increased rate of release over the next years. The most remarkable aspect of the current circumstance is the fact that the CO_2 content of the air is as stable as it is. Clearly, a shift in any of these carbon pools or rates of transfer has the potential for altering the CO_2 content of the atmosphere. This series of shifts is already underway. For this reason, if for no other, the industrialized nations, now scrambling for policies in the management of increasingly scarce supplies of energy, should be considering the implications of their policies for the CO_2 balance of the atmosphere.

If we wait to prove that the climate is warming before we take steps to alleviate the CO_2 build-up, the effects will be well underway and still more difficult to control. The earth will be committed to appreciable changes in climate with unpredictable consequences. The potential disruptions are sufficiently great to warrant the incorporation of the CO_2 problem into all considerations of policy in the development of energy.

II. The Elements of Policy in Management of the World CO_2 Problem

The challenge is obviously worldwide. The problem cannot be resolved by one nation acting alone. However, the U.S. provides leadership on many international issues. The elements of policy proposed here in outline are for the U.S. They apply as well to the world.

1. Acknowledgement of the problem:

The CO_2 problem is one of the most important contemporary environmental problems, is a direct product of industrialization, threatens the stability of climates worldwide and therefore the stability of all nations, and can be controlled. Steps toward control are necessary now and should be a part of the national policy in management of sources of energy.

2. Conservation of fossil fuels:

The first element of any policy that offers the hope of being effective is conservation. Limitation of the rate of exploitation of fuels is possible. The rate is controlled currently by price, taxation, and regulation. It can be controlled as a matter of policy. All actions of government should be reviewed to determine effects on the total use of carbon-based fuels.

3. Choice of fossil fuels:

The choice of fossil fuels and the use made of them bears heavily on the amount of CO_2 released to produce a unit of energy. The production and consumption of liquid or gaseous fuels from coal (synthetic fuels), for instance, is estimated to release 3.4×10^{15} g C per hundred quads (10^{15} Btu) of energy as opposed to 1.45×10^{15} g C for an equivalent amount of energy from natural gas. The difference in CO_2 released is a factor of 2.3 times greater for the coal route to gas than by using natural gas alone. If the coal is burned directly, use of 100 quads of energy releases 2.5×10^{15} g C. These are merely examples. Details appear in Table 1, below.

Fuel	Carbon in 10^{15} g.
OIL	2.0
GAS	1.45
COAL	2.5
COAL: converted to gas or oil (synthetic fuels)	3.4

Table 1. Carbon released in CO_2 per 100 quads of energy released as heat. (One quad = 10^{15} Btu.) (from MacDonald 1978).

4. Reforestation:

It seems elementary that we have reached the point worldwide where the CO_2 problem alone dictates a need to balance the harvest and other transformations of forest with some other storage of carbon. The regrowth of forests is the obvious solution: total respiration, including fires, should be less than or equal to, but not more than, total photosynthesis on a regional and worldwide basis. There are many additional advantages in such a program, quite apart from the advantages gleaned from wise management of the CO_2 problem.

It is our conviction that an appropriate reaction to the mounting worldwide squeeze on supplies of energy requires consideration of the CO_2 problem as an intrinsic part of any proposed policy on energy.

George M. Woodwell
The Ecosystems Center
Marine Biological Laboratory
Woods Hole, Massachusetts

Gordon J. MacDonald
Dartmouth College
Hanover, New Hampshire

Roger Revelle
University of California-San Diego
La Jolla, California

C. David Keeling
Scripps Institute of Oceanography
La Jolla, California

- Selected References -

Bolin, B. and W. Bischof, 1970, Variations of the Carbon Dioxide Content of the Atmosphere in the Northern Hemisphere, Tellus 22, 431-442.

Atmospheric Carbon Dioxide Variations at the South Pole, 1976 A, Tellus 28, 552-564.

Keeling, C.D. et al., 1976 B, Atmospheric Carbon Dioxide Variations at Mauna Loa Observatory, Hawaii, Tellus 28, 538-551.

Kellogg, W.W., 1978, Is Mankind Warming the Earth?, Bulletin of the Atomic Scientists: Feb., 11-19.

Lamb, H., 1977, Climate, Present, Past and Future, Vol. 2, Methuen, London.

MacDonald, G.J.F., 1978, An Overview of the Impact of Carbon Dioxide on Climate, Mitre Corporation, McLean, Virginia 22102.

Manabe, S. and R. Wetherald, 1975, The Effect of Doubling the CO_2 Concentration on the Climate of a General Circulation Model, Jour. Atmos. Sciences 32, 3-15.

Revelle, R. and W. Munk, 1977, The Carbon Dioxide Cycle and the Biosphere in Energy and Climate, Report of the Geophysics Study Committee, National Academy of Sciences, Washington, D.C.

Revell, R. and H. Suess, 1957, Tellus 9, 18-27.

SCEP 1970, Man's Impact on the Global Environment: Assessment and Recommendations for Action, in Study of Critical Environmental Problems, Cambridge, MIT Press.

SMIC 1971, Inadvertent Climate Modification, Report of the Study of Man's Impact on Climate (SMIC), Cambridge, MIT Press, 319 pp.

Woodwell, G.M. and E.V. Pecan (eds.), 1973, Carbon and the Biosphere U.S.A.E.C., Technical Information Center, Springfield, Virginia, 392 pp.

Woodwell, G.M., R.H. Whittaker, W.A. Reiners, G.E. Likens, C.C. Delwiche, and D.B. Botkin, 1978, The Biota and the World Carbon Budget, Science 199, 141-146.

G.M. Woodwell is Director of the Ecosystems Center of the Marine Biological Laboratory and immediate past President of the Ecological Society of America.

Gordon J. MacDonald is Henry R. Luce Professor of Environmental Studies, Dartmouth College, Hanover, New Hampshire. A member of the National Academy of Sciences, he served on the Council on Environmental Quality, Washington, D.C.

Roger Revelle, a member of the National Academy of Sciences, is currently at the University of California at San Diego. He was for eleven years Richard Saltonstall Professor of Population Policy and Director of the Harvard Center for Population Studies.

Charles David Keeling is Professor of Oceanography, Scripps Institute of Oceanography, La Jolla, California.

NCAQ WORKSHOP ON CARBON DIOXIDE
LIST OF PARTICIPANTS

Mr. Thomas Jorling, Moderator	Williams College
Dr. George M. Woodwell	Woods Hole
Dr. Henry Shaw	Exxon
Mr. Rafe Pomerance	Friends of the Earth
Mr. Edward Strohbehn	CEQ
Dr. Lester Lave	Brookings Institution
Dr. Michael Glantz	NCAR
Dr. Edith Brown Weiss	The Georgetown University Law Center
Dr. Hermann Rahn	State University of New York at Buffalo
Dr. John S. Perry	National Research Council
Dr. William Elliott	NOAA
Dr. Donald King	State Department
Dr. William Sommers	Forest Service
Dr. David J. Rose	MIT
Dr. J. A. Laurmann	Stanford University
Mr. David H. Slade	Department of Energy
Mr. Richard D'Amato	Office of Senator Ribicoff
Mr. Mitch Tyson	Office of Senator Tsongas
Mr. David M. Burns	AAAS
Mr. Thomas Waltz	National Climate Program
Mr. John Hoffman	EPA
Mr. Dean Abrahamson	University of Minnesota
Mr. Anthony Scoville	Subcommittee on Science, Research and Technology, U.S. House of Representatives

CO_2 WORKSHOP PARTICIPANTS

David J. Rose - Professor, MIT Nuclear Engineering Department
Expert in energy and energy policy. Participated in National Academy of Sciences Committee on Nuclear and Alternative Energy Systems (CONAES)

Rafe Pomerance - President, Friends of the Earth
Active in Clean Air Act legislation, worked with United Nations Environmental Program, and currently serves on the CO_2 Advisory Committee for DOE

John Perry - Executive Secretary, National Academy of Sciences Climate Research Board
Expert on climate and climate change due to CO_2

Thomas C. Schelling - Professor, Harvard, JFK School of Government
Expert in political science and economics, chairman of the NAS Ad Hoc Study Panel on Economic and Social Aspects of CO_2 Increase

Lester Machta - Director, Air Resources Laboratory, NOAA
Expert on CO_2 trends and climate impact assessments, consultant to DOE CO_2 Program

Donald King - Director, Office of Environment and Health, State Department
State Department expert on CO_2--Relationship to international affairs

Hermann Rahn - Professor, Department of Physiology, State University of New York at Albany
Expert in biomedical impacts of CO_2

David Meserve - Office of Science, Technology and Policy, Executive Office of the President
Staff expert on CO_2 and impacts on policy

Gus Speth - Chairman, Council on Environmental Quality

William Sommers - Principal Research Meteorologist, USDA, Forest Service
Expert on reforestation and impacts of CO_2

Sylvan Wittwer - Associate Dean, Michigan State University School of Agriculture and Natural Resources
Expert on CO_2 impacts on biosphere, consultant to DOE CO_2 Program, and served on NAS Ad Hoc CO_2 Panel

Lester Lave - Brookings Institution
Expert in economics and economic and social impact of CO_2

Joel A. Laurmann - Professor, Mechanical Engineering, Stanford University
Familiar with CO_2 control technologies and analysis of policy changes because of CO_2-induced climate change

Stephen Schneider - Senior Scientist, National Center for Atmospheric Research
Expert in atmospheric CO_2 and climate change, interested in policy responses to CO_2, written numerous papers and provided testimony to Congress on CO_2

Henry Shaw - Exxon
Member API CO_2 Task Force

Thomas Moss - Staff Director, House Subcommittee on Science, Research and Technology
Coordinated CO_2 activities for Rep. George Brown and House Subcommittees, participated in discussions of policy impacts of CO_2

Dick D'Amato - Legislative Aide to Senator Ribicoff
Coordinated and planned Senate Symposium on CO_2

Mitch Tyson - Legislative Aide to Senator Tsongas
Coordinated and planned Senate Energy and Natural Resources Committee Hearings on CO_2

David Burns - American Association for the Advancement of Science
Principal coordinator of AAAS CO_2 Project

George Woodwell - Director, The Ecosystems Center, Marine Biology Laboratory
Expert on carbon cycle, CO_2 trends, atmosphere-ocean interface, served on numerous advisory groups on CO_2, including NAS Ad Hoc Panel

David Slade - Director, DOE CO_2 Research Program
Responsible for developing DOE research program on climate effects of CO_2 and for resultant socioeconomic impacts

Gordon J. MacDonald - Chief Scientist, The Mitre Corporation
Atmospheric scientist expert in CO_2 impacts, concerned about lack of public policy response

Representative of the United Nations Environmental Program