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Summary of the Carbon Dioxide Effects Research and Assessment Program

United States
Department of Energy
The Carbon Dioxide Effects
Research and Assessment Program

CO₂

MASTER

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Summary of the Carbon Dioxide Effects Research and Assessment Program

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Carbon Dioxide Effects
Research and Assessment Program

United States
Department of Energy

Note: This material was prepared in July 1980. Some of the information may not be valid after that date.

**Definition and Significance of the
Carbon Dioxide Issue**

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It is the sense of the scientific community that carbon dioxide from the unrestrained combustion of fossil fuels is potentially the most important environmental issue facing mankind. Current predictions call for a doubling of atmospheric carbon dioxide as early as the middle of the next century. Climate models, using these elevated levels, predict the possibility of significant dislocations in the global distribution of climate. Should such perturbations in the distribution of global temperature, cloudiness, precipitation, and wind occur, then it is clear that there could be major changes in the global distribution of agriculture, in the extent and composition of ecological systems, in the biological and physical characteristics of the oceans, and in the extent of the cryosphere. The costs or benefits of such extensive environmental changes to a balanced international societal system are difficult to estimate but could be historically unprecedented. It is therefore of the utmost importance that the technical community resolve the scientific uncertainties concerning the effect of carbon dioxide on climate and the cascade of environmental and societal impacts resulting from a change in climate as quickly as possible.

The Global Carbon Cycle

This simplified diagram depicts the distribution and exchange of the carbon that is contained in the various environmental reservoirs. Anthropogenic sources, primarily fossil fuel combustion and deforestation, are thought to release as much as 8 billion metric tons of carbon to the atmosphere annually. About half of this remains in the atmosphere and results in the observed increasing CO₂ concentrations. The other half is taken up by the oceans. There are uncertainties in the rate of deforestation, and therefore uncertainties in the flux of carbon from the biosphere to the atmosphere. There are also uncertainties in the flux of carbon from the atmosphere to the oceans. As a consequence, confident predictions of future atmospheric concentrations of CO₂ cannot now be made even if the future rate of combustion of fossil fuels was known.

Exchangeable Carbon Reservoirs and Fluxes

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() = Size of Carbon Reservoirs in Billions of Metric Tons of Carbon

Fluxes (arrows) = Exchange of Carbon Between Reservoirs in Billions of Metric Tons of Carbon per Year

Trend in Atmospheric CO₂ Concentrations

This chart shows the observed increase in atmospheric CO₂ concentrations. Although these concentrations were measured at the Mauna Loa Observatory in Hawaii, they are typical of those measured anywhere else in the world. The annual cycle is attributed to the cycle of photosynthesis and decay in the Northern Hemisphere. Similar records have been obtained at the South Pole and elsewhere in the Northern Hemisphere. While there are regional differences in the absolute magnitude of the concentration, the worldwide increase, currently approximately 1/3 of 1% per year, is well documented.

Source: Charles D. Keeling, et. al.; "Carbon Dioxide Variations at Mauna Loa Observatory, Hawaii," *Tellus*, Volume 28, 1976, p. 538 (updated by MACHTA, ARL, NOAA)

Trend in Atmospheric CO₂ Concentrations

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Source: Keeling, 1976 (Updated by MACHTA)

Projections of Future CO₂ Emissions and Atmospheric Concentration

Because of uncertainty in the rate of carbon release from storage by the clearing of tropical forests, estimates of the fraction of the carbon dioxide produced that remains in the atmosphere are subject to wide bands of possible error. This figure shows the effect of high estimates versus low estimates for forest clearing in comparison to the increases in the atmospheric CO₂ concentration since the end of World War II.

Projections of the future depend on the assumed energy use scenario as well as the rate assumed for continued forest destruction. The solid and dashed curves starting at the present time depict a high fossil energy future and a low fossil energy future and show a range of cumulative CO₂ production for both a high rate of forest clearing and a low rate of clearing. Note that by the middle of the next century the cumulative production is determined mostly by the energy future scenario assumed — forest clearing gives only a very small proportion of the total.

However, the amount of CO₂ produced from the clearing of forests in the recent past is fundamental to the understanding of the carbon cycle and in the determination of the "air-borne-fraction." If forest clearing has occurred at a high rate, the airborne fraction is smaller than if the clearing of forests has been less. For each combination (forest clearing and fuel use), the estimate of the amount of CO₂ retained in the atmosphere falls within the shaded area. Uncertainties in past and future forest clearing, uncertainties in the carbon cycle, and uncertainties in the future demand for fossil fuel are all coupled in the shaded area giving a window in time for the atmosphere to reach a given concentration.

Source: R.M. Rotty, "Uncertainties Associated with Global Effects of Atmospheric Carbon Dioxide," Oran/IEA Report No. 79-6, Oak Ridge Associated Universities, 1979.

Projections of Future CO₂ Emissions and Atmospheric Concentration

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Source: Rotty, 1979

Effects on Climate

Carbon dioxide, although virtually transparent to short wave solar radiation (visible light) strongly absorbs long wave radiation (heat) at certain wave lengths in which other atmospheric gases are transparent. Thus, when carbon dioxide increases, more long wave radiation is trapped in the earth atmosphere system than would otherwise be the case. Some of this radiant energy increases evaporation. The increase of atmospheric water vapor resulting from the increased evaporation amplifies the "greenhouse" effect because water vapor also strongly traps long wave radiation. Because of differences in incoming solar radiation with latitude and because of the complex nature of the earth's surface (water, land, ice), the CO₂ induced warming is not uniform over the globe.

The accompanying diagram shows the results of a numerical simulation (a computer model) of the effects on global temperature of a doubling of atmospheric CO₂. It shows the temperature differences, averaged longitudinally, between a "run" with current values of atmospheric CO₂ and a "run" with twice that amount. Note particularly the larger than average increases of temperature in the polar regions and the decreased temperatures in the stratosphere. Other, more recent models suggest that, in addition to the temperature changes, a doubling of atmospheric concentration values may result in decreased soil moisture in the mid-latitudes, increased precipitation in the Arctic, and changes in atmospheric circulation.

Source: S. Manabe and R. Wetherald, "The effects of Doubling the CO₂ Concentration on the Climate of a General Circulation Model," *Journal of the Atmospheric Sciences*, Volume 32, 1975, p. 3

Temperature Change (°C) Due to Doubling CO₂ Concentrations

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Source: Manabe and Wetherald, 1975

Regionality of Future Climate

It is unlikely that an overall warming of the lower atmosphere would be evenly distributed. The map opposite is shown to emphasize this point. It gives a preliminary comparison of today's climate with the earth's climate about 4000 to 8000 years ago, when the average temperature was probably higher than today. Note the apparent changes in precipitation, some areas being wetter than today, some being drier. Regional changes in precipitation could be more important environmentally than changes in regional temperature.

Source: W.W. Kellogg, "Is Mankind Warming the Earth?" *Bulletin of the Atomic Scientists*, Volume 34, Number 2, Feb. 1978, P. 17

The Altithermal Period

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Source: Kellogg, 1978

Implications of CO₂ Induced Climatic Change

Effects such as these, even were they to occur, would not be expected until early in the next century. The reason for a certain urgency to accelerate the research now is that it could take as long as a half century to realign the global energy generation system if it appears that a carbon dioxide effect calls for such an initiative.

Implications of CO₂ Induced Climatic Change

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- **Should carbon dioxide increase and climate change to the degree now thought possible, the hydrosphere, biosphere, lithosphere, and cryosphere would all be affected.**
- **Some of these effects, such as the melting of the Arctic Ocean's icepacks or increases in evaporation and cloudiness, would constitute geophysical "feedbacks" to the climatic system thus increasing or decreasing the magnitude of the climatic change.**
- **Other environmental changes might not affect the geophysical processes but would be important in themselves. Examples of these changes are changes in the viability of crops, in the species composition of the "wild" biosphere or in the chemistry of the upper layers of the oceans.**
- **It is thought that these changes in climate and the environment would not be globally uniform.**
- **The impact of unprecedentedly large, regionally uneven environmental changes would almost certainly affect all aspects of the global economic, political, and social systems in an unknown but potentially profound manner.**

The Carbon Dioxide Program Goal

- Recognizing the potential importance of the carbon dioxide issue to the policy requirements of the National Energy Organization Act of 1977, a goal for a national carbon dioxide effects research and assessment program was defined.
- Note particularly that "consequences" are stressed. These may be economic, social or environmental. Note also that, to be useful as a basis for policy decisions, statements of consequences must be accompanied by statements of the confidence of the estimates.

The Carbon Dioxide Program Goal

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To develop the ability to predict the agricultural, environmental, and societal consequences, both national and international, of increasing atmospheric concentrations of carbon dioxide with sufficient confidence to permit informed policy decisions to be made on the use and development of energy and other resources.

Strategic Approaches to the Goal

Three strategies were adopted in order to begin the effort required to address this unprecedented issue.

Strategic Approaches to the Goal

**Carbon Dioxide Effects
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- I. To create a national and international focus for the carbon dioxide effects issue.**
- II. To provide the scientific basis for energy policy related to the carbon dioxide issue by developing and maintaining a comprehensive research program.**
- III. To conduct the information synthesis and analyses required to provide predictions of social costs required for policymaking and to determine mechanisms for increasing the confidence in those predictions.**

Strategy I: The Focus

The Department of Energy created an institutional structure to provide the focus for the program.

The roles of the elements of the structure are:

- **Carbon Dioxide and Climate Division, Office of Health and Environmental Research.** To develop and direct the DOE Carbon Dioxide Research and Assessment Program.
- **Science Directorate.** To serve as the linkage between the scientific community and the DOE. The Science Directorate is composed of leading and active scientists in the various areas of study.
- **Review, Integration and Evaluation (Assessment).** To conduct the evaluation of the consequences of the carbon dioxide issue.
- **Advisory Committee.** To provide independent advice to the Assistant Secretary for the Environment and the Carbon Dioxide and Climate Division on the conduct, plans and management of the program.
- **National Climate Program Office.** The national focus for United States climate programs created by the National Climate Program Act of 1978 (P.L. 95-367).
- **Interagency Committee on Carbon Dioxide and Climate.** This Committee, chaired by the DOE, is the National Climate Program Office's instrument to insure a coordinated National Program on Carbon Dioxide, Environment and Society.

**Carbon Dioxide and
Climate Research Program**

**Carbon Dioxide Effects
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Strategy II: The Development of the Research Program

- The DOE set out to create a science plan of unquestionable authority to govern its research.
- It is intended that the science plan be executed as a cooperative federal enterprise and be coordinated with the international community.
- The development of the science plan involves:
 1. A workshop of leading active scientists. As a result of the Workshop, DOE identifies:
 2. Research Issues for which the Science Directors are asked to prepare:
 3. Research Issue Papers which are scientific plans for the conduct of a research program to address each issue. The Issue Papers are assembled by:
 4. The Science Director into:
 5. A Comprehensive Plan for Carbon Dioxide Effects Research and Assessment. The Comprehensive Plan is distributed widely for:
 6. Review by the Science Directorate, other scientists, DOE and other government personnel after which it is distributed to the public and to:
 7. Congress and the Executive as part of the budget review process. Finally:
 8. The Carbon Dioxide and Climate Division implements the approved, funded research program.

OUTLINE OF THE RESEARCH AND ASSESSMENT PROGRAM

The entire program is divided into six areas. Each is described below:

I. Research on the Carbon Cycle

Research in this category deals with the issue of determining the transient and final fate of carbon dioxide released to the atmosphere by fossil fuel combustion. Research on the role of the biosphere and oceans as sources and sinks is included. Models to estimate future atmospheric CO₂ levels for various scenarios of fossil fuel use and land management practices are developed. Atmospheric concentrations of CO₂ are measured by a worldwide network in a cooperative program with the National Oceanic and Atmospheric Administration.

II. Research of CO₂ and Climate

This research area includes studies to determine the effects of increasing CO₂ concentrations on the global atmosphere and its component parts. Included are studies of the global radiative balance and temperature and moisture structure and circulation. This area also includes studies of the interaction and feedback between the atmosphere and the oceans, terrestrial land masses, and biota and cryosphere. Retrospective evidence of climate and CO₂ relationships is included. Current atmospheric data will be evaluated to search for evidence of climate change.

III. Research on the Effects of Climate Change and Carbon Dioxide Increase on the Remainder of the Environment

This research area, the first development of which is being undertaken in this Program, deals with the joint impact of a change in the climate system and increasing atmospheric CO₂ concentrations. Attention is directed toward the interactions between the changed atmospheric state and ocean circulation, chemistry, and biology, the extent and stability of the marine and terrestrial-based cryosphere, the global and regional agricultural systems and the major components of the natural terrestrial biosphere. Feedbacks and other interaction between the oceans, cryosphere, terrestrial biosphere and the atmospheric system are included.

**Program Development Outline
Process for Developing the Carbon
Dioxide Research Program Plan and
Obtaining Its Federal Acceptance**

**Carbon Dioxide Effects
Research and Assessment Program**

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OUTLINE OF THE RESEARCH AND ASSESSMENT PROGRAM

OUTLINE OF THE RESEARCH AND ASSESSMENT PROGRAM (Cont.)

IV. Research on the Social and Economic Consequences of Carbon Dioxide-Induced Climate Change

This research area includes studies of the impact of a change in the total environmental system on the global social and economic order. Investigations will include historical case studies, regional studies and studies of the perception of information. Methodologies for the systematic construction of social and environmental scenarios will be developed. The magnitude and type of current international stresses and their potential exacerbation will be investigated.

V. Research on the Amelioration of Global and Sectoral Impacts

Research in this area consists of studies of strategies and technological initiatives to (a) minimize the rate of CO₂ buildup and, (b) permit ordered and planned societal adaptation to unavoidable environmental dislocations.

VI. Review, Integration and Evaluation

The functions of this program area are

- to determine the environmental, economic, political and social costs/benefits resulting from increasing levels of CO₂
- to determine the costs/benefits of strategies or technological initiatives that could be taken to mitigate or take advantage of the consequence of a CO₂ increase
- to determine whether the global research program is properly directed to the remaining and important uncertainties

OUTLINE OF THE RESEARCH AND ASSESSMENT PROGRAM (Continued)

Strategy III: The Review, Integration and Evaluation (Assessment)

The role of this strategic element in the total Program is shown in the diagram on the adjoining page. It should be recognized that

- there is a very large body of “supporting” research that is considered by the Assessment Program; research that is not specifically a part of the Carbon Dioxide Program itself,
- individual research undertakings often do not fit easily into one or another of the research “bins” which are intended primarily for program display purposes, and
- while the assessment process is shown as sequential, in reality the various activities are usually simultaneous.

A NATIONAL PROGRAM ON CARBON DIOXIDE, ENVIRONMENT AND SOCIETY

**Publications of the
Carbon Dioxide and Climate Division**

CO ₂ Report NR.	Title
001	Workshop on the Global Effects of Carbon Dioxide from Fossil Fuels, May 1979
002	Summary of the Carbon Dioxide Effects Research and Assessment Program
003	The Role of the Temperate Zone Forests in the World Carbon Cycle (Workshop), February 1980
004	The Role of Organic Soils in the World Carbon Cycle (Workshop), February 1980
005	Carbon Dioxide Research Progress Report Fiscal Year 1979, April 1980
006	Environmental Control Technology for Atmospheric Carbon Dioxide, May 1980
007	The Role of Tropical Forests on the World Carbon Cycle (Symposium), in preparation
00?	Workshop on Environmental and Societal Consequences of a Possible CO ₂ -Induced Climate Change, in preparation
00?	Research Issues — The National Program on Carbon Dioxide, Environment and Society, in preparation
00?	A Comprehensive Plan for Carbon Dioxide Effects Research and Assessment—Part I: The Global Carbon Cycle and Climatic Effects of Increasing Carbon Dioxide, May 1978 (revision in preparation)
00?	A Comprehensive Plan for Carbon Dioxide Effects Research and Assessment—Part II: Environmental and Societal Consequences of a Possible CO ₂ -Induced Climate Change, in preparation

**Publications of the Carbon Dioxide
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Transition to a National Program

- The DOE objective of establishing a national, and then international, focus for the CO₂ issue was moved forward rapidly by the passage of the Climate Program Act (Public Law 95-367) and the establishment of the National Climate Program Office.
- The Climate Program Office asked the Department of Energy to take the lead in developing a plan for a National Carbon Dioxide, Environment and Society Program for inclusion in the National Climate Program Plan.
- Characteristics of the National Program are:
 - Research:** The National Research Program Plan will probably not differ significantly from the DOE plan since the intent of DOE has always been to develop a National Program. There will, however, be increased participation by other agencies.
 - Assessment:** DOE will continue to have the responsibility for the Review, Integration and Evaluation (Assessment) Program.
 - Management:** The action flow of the management activity is as shown in the accompanying diagram:
 1. Scientific planning will be accomplished by the active scientific community.
 2. Converting the Science Plan to a National Program on Carbon Dioxide, Environment and Society will be the responsibility of an Interagency Committee of the Climate Program Office chaired by DOE.
 3. Policy issues in the Program Plan will be addressed by the Climate Program Policy Group created by the Climate Program Act.
 4. Coordination of carbon dioxide planning with the National Climate activity will be accomplished by the National Climate Program Office. The office will also be a primary interface with multinational and international institutions.
 5. The coordinated carbon dioxide program Plan will be executed, according to the agreements reached by the Interagency Committee, by each agency following its own procedures for conducting research.
 6. A periodic assessment will be prepared by the DOE.

**Carbon Dioxide Effects
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The flowchart illustrates the U.S. Climate Change Research Program Planning and Coordination process, showing the flow of information and decision-making among various entities. The process is numbered 1 through 6:

- (1) Science Planning**: Initiated by **Information from All Other Sources** and **Information from DOE**. It is **Chaired by DOE** and **Includes Other Agencies, under Auspices of CPO**.
- (2) Research Program Planning and Coordination**: Led by the **Scientific Community**.
- (3) Climate Policy Development Review and Endorsement**: Led by the **CPO Policy Group**.
- (4) Climate Coordination**: Led by the **CPO**. It has a **State Dept.** and **International Institutions** interface.
- (5) Research Program Execution**: Led by **Agencies**.
- (6) Review, Integration and Evaluation (Assessment)**: Led by **DOE**. It receives input from **Information from All Other Sources** and **Information from DOE**.

The process flows from (1) to (2), (2) to (3), (3) to (4), (4) to (5), and (5) to (6). There is also a direct flow from (6) back to (1).

**Status Reports of the
Carbon Dioxide Issue**

Carbon Dioxide Effects
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In the fifth and tenth year of the program, 1984 and 1989, a comprehensive, authoritative analysis report will be issued. The assessment report will represent an international consensus of the perceived costs or benefits of the carbon dioxide issue and the confidence that can be placed in those estimates. In addition, the first of these reports will determine the effectiveness of the international research program and will recommend appropriate research reorientations.