# HUMAN INTERACTIONS WITH THE CARBON CYCLE

## Summary of a Workshop

Paul C. Stern

Committee on the Human Dimensions of Global Change
Division of Behavioral and Social Sciences and Education

National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C.

**NATIONAL ACADEMY PRESS • 2101 Constitution Avenue, NW • Washington, DC 20418**

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This study was supported by Contract/Grant No. NASW-01008 between the National Academy of Sciences and the National Aeronautics and Space Administration. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number 0-309-08420-2

Additional copies of this report are available from National Academy Press, 2101 Constitution Avenue, NW, Lockbox 285, Washington, DC 20055; (800) 624-6242 or (202) 334-3313 (in the Washington metropolitan area); Internet, http://www.nap.edu

Printed in the United States of America



Suggested citation: National Research Council. (2002). *Human Interactions with the Carbon Cycle: Summary of a Workshop*. Paul C. Stern. Committee on the Human Dimensions of Global Change. Division of Behavioral and Social Sciences and Education. Washington, DC: National Academy Press.

# THE NATIONAL ACADEMIES

National Academy of Sciences
National Academy of Engineering
Institute of Medicine
National Research Council

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Wm. A. Wulf is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. Wm. A. Wulf are chairman and vice chairman, respectively, of the National Research Council.

## COMMITTEE ON THE HUMAN DIMENSIONS OF GLOBAL CHANGE

THOMAS DIETZ *(Chair)*, Department of Environmental Science and Policy and Department of Sociology and Anthropology, George Mason University
BARBARA ENTWISLE, Department of Sociology, University of North Carolina
MYRON GUTMANN, Department of History, University of Texas at Austin
RONALD MITCHELL, Department of Political Science, University of Oregon
EMILIO MORAN, Department of Anthropology, Indiana University
M. GRANGER MORGAN, Department of Engineering and Public Policy, Carnegie Mellon University
EDWARD PARSON, John F. Kennedy School of Government, Environment and Natural Resources Program, Harvard University
ALAN RANDALL, Department of Agricultural, Environmental, and Development Economics, Ohio State University
PETER J. RICHERSON, Division of Environmental Studies, University of California, Davis
MARK ROSENZWEIG, Department of Economics, University of Pennsylvania
STEPHEN H. SCHNEIDER, Department of Biological Sciences, Stanford University
SUSAN STONICH, Department of Anthropology and Environmental Studies Program, University of California, Santa Barbara
ELKE U. WEBER, Department of Psychology, Columbia University
THOMAS J. WILBANKS, Oak Ridge National Laboratory, Oak Ridge, Tennessee
CHARLES KENNEL *(ex officio, chair, Committee on Global Change Research)*, Scripps Institution of Oceanography, University of California, San Diego
ORAN R. YOUNG *(ex officio, International Human Dimensions Program Liaison)*, Institute of Arctic Studies, Dartmouth College

**Staff**

PAUL C. STERN, *Study Director*
DEBORAH M. JOHNSON, *Senior Project Assistant*

# Acknowledgments

The Committee on the Human Dimensions of Global Change is grateful to the many individuals whose efforts made this workshop summary possible. The committee's work and other work of the National Research Council in support of the U.S. Global Change Research Program (USGCRP) is supported by a contract with the National Aeronautics and Space Administration, acting on behalf of the USGCRP agencies.

We also wish to thank the workshop speakers, whose remarks stimulated a rich and wide-ranging discussion (see the Appendix for the workshop agenda). Committee members, as well as workshop participants, contributed questions and insights that significantly enhanced the dialogue. The workshop was conceived by the committee, with organizational responsibility delegated to a planning group consisting of the chair, Thomas Dietz, and members Emilio Moran, Edward Parson, and Thomas J. Wilbanks. This summary was executed by Paul C. Stern, staff director of the committee, to reflect a factual summary of what occurred at the workshop.This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the Report Review Committee of the National Research Council. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report: David Cash, John F. Kennedy School of Government, Harvard University; Clark C. Gibson, Department of Political Science, University of California, San Diego; Diana Liverman, Center for Latin American Studies, University of Arizona; and Robert Mendelsohn, School of Forestry and Environmental Studies, Yale University.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the final draft of the report before its release. The review of this report was overseen by Oran R. Young, Institute of Arctic Studies, Dartmouth College. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the author and the institution.

# Contents

# Background

The carbon cycle has recently become interesting to policy makers. It has been of scientific interest for a long time because life on earth depends on it. Carbon dioxide released by the respiration of all living organisms is taken up by plants, which use it in the process of photosynthesis, in which the carbon is fixed as organic matter and the oxygen is released back into the atmosphere, thus providing food for other organisms and replenishing the oxygen needed to support metabolism. What has made the carbon cycle interesting to policy makers is its relationship to global climate change: increased releases of carbon-containing "greenhouse gases" account for the great majority of "radiative forcing" or increased net retention of solar radiation, which is the primary source of the threats of floods, droughts, intense storms, and the other potential disasters that might result from global warming (see Figure 1).

This increased radiative forcing is quite clearly the result of human interactions with the carbon cycle. Figure 2 illustrates the point for carbon dioxide: for over 400,000 years, the atmospheric concentration of carbon dioxide fluctuated between about 180 and 280 parts per million; in the past 100 years, it has shot up to almost 350 and it is expected to continue rising rapidly. Nothing but human activity can explain this unprecedented change. The same is true for changes in the atmospheric concentrations of methane and the chlorofluorocarbons. The main human activities that contribute to climate change are shown in Figure 3. It is easy to see the predominant importance of carbon-related activities, including fossil fuel

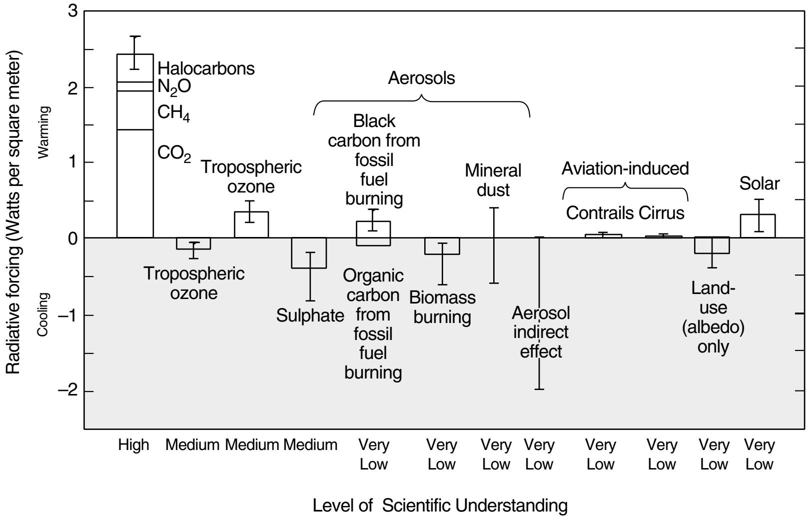


FIGURE 1 Global mean radiative forcing of the climate system for the year 2000, relative to 1750. Source: Working Group I, Intergovernmental Panel on Climate Change (2001).

and chlorofluorocarbon use, biomass burning, and paddy rice and cattle production, in this picture.

The U.S. Global Change Research Program (USGCRP) has identified the global carbon cycle as a major program element, allocating $221 million of its $1.6 billion budget for 2002 to it (Subcommittee on Global Change Research, 2001). An interagency Carbon Cycle Working Group, advised by an outside scientific steering committee and guided by a Carbon Cycle Science Plan (CCSP, Sarmiento and Wofsy, 1999) sets research directions for this effort. The CCSP and the scientific steering committee strongly reflect the intellectual concerns of fields of natural science that study the cycling of carbon through the atmosphere and the biosphere. Although the CCSP notes the critical role of human activities in perturbing the carbon cycle, it does not include any research on these activities. The U.S. government's carbon cycle research activity has not yet integrated the relevant fields of the social and behavioral sciences.

It is in this context that the USGCRP's Carbon Cycle Working Group asked the National Research Council's Committee on the Human Dimensions of Global Change to hold a workshop on Human Interactions with

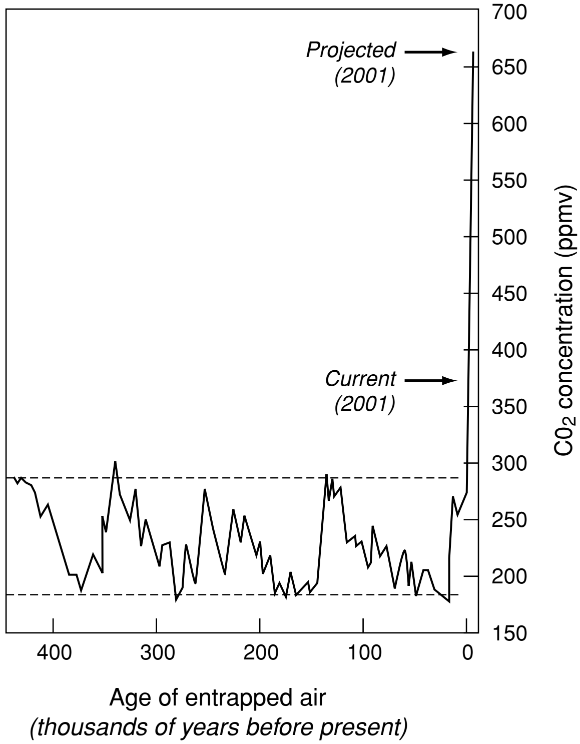


FIGURE 2 Atmospheric carbon dioxide concentration over the past 400,000 years. Past data from Vostok ice-core record; future projections from IPCC Third Assessment "business as usual" scenario. Sources: Hibbard et al. (2001). Vostok ice core data from Petit et al. (1999); projection from Prentice et al. (2001).

the Carbon Cycle. The basic purpose of the workshop was to help build bridges between the research communities in the social sciences and the natural sciences that might eventually work together to produce the needed understanding of the carbon cycle—an understanding that can inform public decisions that could, among other things, prevent disasters from resulting from the ways humanity has been altering the carbon cycle. Members of the working group hoped that a successful workshop would improve communication between the relevant research communities in the natural and social sciences, leading eventually to an expansion of the carbon cycle program element in directions that would better integrate the two domains.

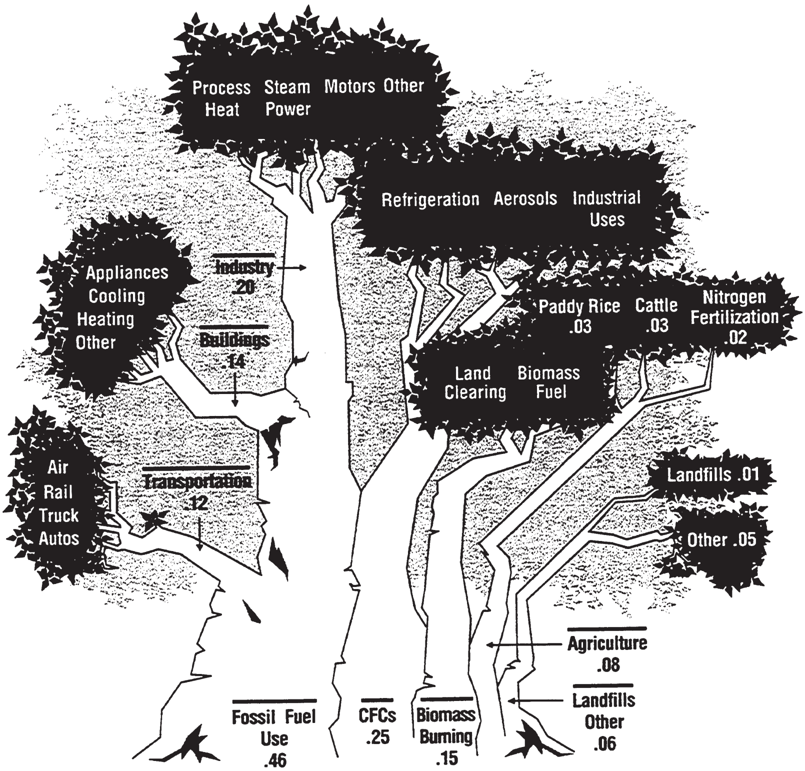


FIGURE 3 Relative contributions of human activities to greenhouse warming, late 1980s. Source: National Research Council (1992).

In planning the workshop, the committee and the working group considered organizing it around carbon cycle issues as they might be seen by social and behavioral scientists. A workshop organized in this way might have helped increase interest in carbon cycle research among social scientists by showing the relevance to the carbon cycle of existing bodies of research on (a) human activities that affect the carbon cycle (e.g., on energy modeling; on the underlying causes of fossil fuel consumption, agricultural intensification, and other major carbon-related human activities; and on the diffusion of technology in agriculture and energy production) and on (b) human activities that respond to the carbon cycle (e.g., on the creation and maintenance of environmental management regimes; on integrated assessment modeling; and on disaster preparedness). It was finally decided, however, that it would be more useful at present to treat the USGCRP's carbon cycle researchers as the primary audience. The workshop was therefore organized to focus on a small number of issues that are already recognized as important by this group and for which the relevance of the social sciences is readily apparent. A possible outcome was that the carbon cycle research effort would move in directions that would encompass such issues. The workshop did not attempt to develop or even outline a comprehensive research agenda on human interactions with the carbon cycle.

Thus, the workshop, which was held in Washington on November 5, 2001, addressed the following three substantive topics (see the Appendix for the agenda and a list of the participants):

- The future of fossil fuel consumption
- Carbon implications of future land use/land cover transformation
- Modeling human interactions with the carbon cycle.

# Main Themes

The main themes raised in the workshop are summarized in this section; the rest of this report provides more detail on the presentations and discussions.

A major theme at the workshop was the increased recognition, particularly among natural scientists working on the U.S. Carbon Cycle Science Plan (CCSP) in the field, of the importance of human activities to the carbon cycle. Comments at the workshop indicated that the CCSP is increasingly interested in human activities for at least three reasons:

• The role of human activities in shaping the terrestrial carbon sink is greater than previously believed. Christopher Field, who heads the CCSP Scientific Steering Committee, stated that the CCSP's research is addressing only about a third of the carbon sink in the United States and that the rest must be understood by examining human activities. These activities include land cover transformation, the suppression of fires, a shift from open dumping of waste to landfilling, and changes in agricultural management. Understanding of such activities is critical for estimating the future size of the sink.

• Carbon cycle projections are more sensitive to uncertainties about carbon emissions than to uncertainties about the natural science of the carbon cycle.

• An increased interest in developing models that lead to atmospheric concentrations that might be set as policy targets (sometimes including sequestration targets) has raised questions about the human implications and feasibility of reaching these targets.

Discussions at the workshop generated a series of research suggestions (see Box 1) in response to the interests of participants associated with the CCSP. Among the recurring themes in these suggestions were three substantive research needs linking human activities and the carbon cycle:

*1. Need to analyze, test, and improve social assumptions in emissions models and scenarios.* Existing models and scenarios are built on unrealistic social assumptions and are not well supported by relevant theory or data. They do not include intelligent agents or represent feedbacks among model elements (e.g., response of human fertility to changing economic conditions and age distributions; response of consumption and income distribution to changes in trade). Analyses of the models could rule out some scenarios as socially impossible or at least allow for estimates of differential likelihood among scenarios. They could also lead to future scenarios based on more realistic assumptions about social processes. Regional-level studies and models can help strengthen understanding of human dimensions of the carbon cycle.

*2. Need for better process understanding of how social and economic forces drive the carbon cycle*. Topics mentioned included the driving forces of energy use in developing countries, the sources of "endogenous" technological change, the intended and unintended effects of past policies, and the causes of rapid changes in human activity and lifestyles (e.g., recent worldwide fertility decline; patterns of increasingly consumptive living). Understanding of these processes would be facilitated by good historical records. It may also require developing new indicators—for example, indicators of energy services, distinct from energy consumption, that can facilitate analysis of development paths that decrease the carbon intensity of economic development.

*3. Need for better analyses working backward from policy objectives*. These analyses identify the policy and behavioral changes required to achieve a given environmental outcome rather than identifying the environmental outcomes likely to arise as a result of given policy and behavioral changes. They can be used to assess the feasibility of policy targets, including sequestration policies.

**BOX 1**
**Some Suggestions for Future Research, with Examples**

**Substantive Research Needs**

Analyze, test, and improve social assumptions underlying emissions models and scenarios

- responses of human fertility to economic conditions
- responses of consumption to changes in trade

Improve process understanding of how social and economic forces drive the carbon cycle

- driving forces of energy use
- sources of "endogenous" technological change
- intended and unintended effects of past policies
- causes of the recent rapid worldwide fertility decline
- causes of patterns of increasingly consumptive living
- development of indicators (e.g., energy services)

Develop better analyses working backward from policy objectives

**Cross-Cutting Activities**

Build a long and continuing historical record of human activities shaping the carbon cycle

- land use/land cover transformations
- fossil fuel use
- environmental policies and treaties
- land management practices
- social drivers of carbon sources and sinks

Develop emissions scenarios independently of the intergovernmental process

Use regional analyses to:

- scale up to the regional level
- compare across regions
- investigate interactions across scales

Give more attention to uncertainties in data and scenarios

- quality of "backfilled" data
- use of models to elaborate uncertainties
- estimate likelihoods of scenarios

In addition, four major themes cutting across substantive research areas also repeatedly arose in workshop discussions:

1. *Need for a long and continuing historical record of human activities shaping the carbon cycle.* A long observational record of key activities (e.g., land use/land cover transformations, fossil fuel use, environmental treaties and policies, and agricultural land management practices) could be built from historical sources and from archaeological data, supplemented by remotely sensed data for recent times. Such data are necessary to quantify the trajectory of carbon sources and sinks in terms of social as well as biophysical drivers, to account for their current state, and to project future effects of human activities on the carbon cycle. A good historical record would provide the observational base needed for research on the substantive themes just noted, as well as for other substantive research on human interactions with the carbon cycle. Some of the necessary data collection is being done in two major international research programs, on Land Use/Land Cover Change (LUCC) and Past Global Changes (PAGES). However, because these programs have their own independent research priorities, this work is often not explicitly linked to the carbon cycle.

2. *Need to develop emissions scenarios independently of the intergovernmental process* so that plausible but politically unpalatable scenarios can be given due consideration.

3. *Value of regional analyses for integrating the social sciences and natural sciences.* Regional analyses, possibly including focused studies of selected regions, can provide venues for better interdisciplinary integration. Regional work should include efforts to scale up to the region (e.g., by using household-level data or agent-based models), analyses across regions (e.g., by comparing multiple case studies), and investigation of interactions across scales.

4. *Need for more attention to uncertainties in scenarios and data.* More attention is needed to the quality of data used as input to models, especially when data were estimated by "backfilling" methods. Models could be used to identify and elaborate uncertainties, and there could be stronger efforts to estimate the likelihoods of scenarios.

# Workshop Presentations and Discussions

## HUMAN DIMENSIONS IN NATIONAL AND INTERNATIONAL CARBON CYCLE RESEARCH

The workshop began with discussions of the place of human dimensions research in two major carbon cycle research initiatives—one within the U.S. Global Change Research Program, and an international one sponsored by three international global change research programs.

### The U.S. Carbon Cycle Science Plan (CCSP)

Speaker: *Christopher Field, Carnegie Institution of Washington*

Field noted that the CCSP began with a geophysical perspective on the caarbon cycle and aimed to identify a small number of new research initiatives. He summarized the stated goals of the plan (Sarmiento and Wofsy, 1999), which was distributed to the participants. Field noted that not much attention has been paid to emissions trajectories. Human dimensions research is not currently part of the plan because "we haven't presented a compelling agenda." He noted, however, that recent research shows that human activity has a much greater influence on the processes central to the CCSP than previously believed.

He reported that the CCSP has already led to the creation of carbon cycle initiatives in several agencies and to an effort to develop a North

American research plan in cooperation with scientists in Canada and Mexico.

The CCSP plan begin with a strong focus on the problem of the "missing carbon sink" that must exist to account for the fact that much of the carbon being released into the atmosphere by human activities fails to show up as an increase in atmospheric $CO_2$ concentration. There is a major policy interest in projecting the future capacity of the sink because it may strongly affect projections of the effects of future carbon emissions on climate. Most researchers have worked from two main hypotheses: that there is a large terrestrial carbon sink and that increases in oceanic carbon dioxide levels are also important to study.

The terrestrial carbon sink is believed to result from some combination of the following: (1) increased net primary productivity due to carbon and nitrogen fertilization from human activity and longer growing seasons associated with global warming; (2) decreases in the rate of disturbance of vegetation by fires; (3) recovery of vegetation from past disturbances (e.g., reforestation); and (4) other sources (including sediment burial in reservoirs, storage of carbon in wood products, and "pseudosinks" caused by transport of carbonaceous products such as food from one part of the world to another). Until recently, it was widely believed that the largest portion of the terrestrial sink was due to carbon dioxide fertilization of plants as a result of increased atmospheric carbon concentrations. Recent evidence is changing that view. Change in land cover due to human activity and the suppression of fires in the United States are now considered much more important than previously believed. In addition, a shift from open dumping of waste to landfilling and changes in agricultural management may also contribute significantly to the sink. Some of these changes involve only one-time and temporary increases in the sink, and some (such as fire suppression) may even be undergoing reversal. All these emerging understandings suggest that improved understanding of human actions on the land is critical for understanding the carbon sink and its future. Field's assessment is that the CCSP's research is addressing only about a third of the carbon sink in the United States (the portion due to carbon fertilization of plants) and that the rest must be understood by examining human activity.

Field noted several emerging issues in the understanding of carbon sinks:

• The terrestrial sink was larger in the 1990s than in the 1980s. The reasons are unknown but probably involve human activity.

• There are important terrestrial sinks in the tropics as well as in the temperate zone. They probably operate under different mechanisms from temperate sinks.

• Major gaps in knowledge are being identified, including (a) the contributions of different mechanisms to the sinks and to the trajectory of their size over time, (b) interactions of human activities with background processes, and (c) interactions of human efforts to manage the sinks with other policy goals.

## International Carbon Cycle Research Activities

Speaker: *Eugene Rosa, Washington State University*

Eugene Rosa referred to several international efforts, including some university-based efforts in Europe and the Global Carbon Project of the International Geosphere-Biosphere Program (IGBP), the International Human Dimensions Program (IHDP), and the World Climate Research Program (WCRP). The descriptions of the Carbon Challenge Project (Hibbard et al., 2001) and of the IHDP component of it (Gupta et al., 2001) were distributed to workshop participants (see Box 2 for a brief summary).

Rosa noted that sustainability was the core concept of several of the international efforts. The goal is to build a theoretical framework for integrated assessment of the carbon cycle and a global observation system linked to theory.

Rosa contrasted the approach of the international activities with that of the U.S. CCSP. He said that the CCSP treats human activities as a residual category, even though they seem to be responsible for most of the dynamics of the carbon cycle of interest to the program. By contrast, human activity is central in the international Global Carbon Project (GCP). (Figure 4, taken from the GCP's foundation document, illustrates the difference between a view of the carbon cycle that considers only biogeochemical processes and one that integrates human activities as well.) Rosa quoted its program description as follows (Hibbard et al., 2001:4):

> The project's framework provides an integrated perspective across disciplines as well as national boundaries. The approach is to accept that humans and

**BOX 2**
**Some U.S. and International Carbon Cycle Research Programs**

**U.S. Carbon Cycle Science Program**

Part of the U.S. Global Change Research Program, this activity includes projects funded by several different federal agencies and linked together by the Carbon Cycle Science Plan (Sarmiento and Wofsy, 1999) and presumably future programmatic statements organized by the program's scientific steering committee. It also has links to the international Carbon Challenge Project (see below) and presumably will make a major contribution to the research goals of that project.

**The Global Carbon Project**

This international effort is organized by the same three international scientific organizations that have coordinated on global change research for over a decade: the International Geosphere-Biosphere Program (IGBP), the World Climate Research Program (WCRP), and the International Human Dimensions Program on Global Environmental Change (IHDP). Its goal (Hibbard et al., 2001:13) is to develop "a single, unified, mutually agreed framework and the mechanisms for exchanging information, . . . identify research gaps and lessen redundancy of effort . . . [and] to coordinate national and disciplinary efforts within the international and multidisciplinary joint framework to tackle global-scale carbon-cycle questions that cannot be answered otherwise." The project is funded internationally, with support from U.S., European Community, Australian, and Japanese government sources.

**IHDP Global Carbon Cycle Research**

This effort is the IHDP's contribution to the Global Carbon Project. IHDP has developed a conceptual framework (Gupta et al., 2001) relating the carbon cycle to the major research themes of human dimensions research being pursued by the IHDP (land use/land cover change, institutional dimensions of global environmental change, industrial transformation, and human security). This framework may facilitate linkages between work on these themes and carbon cycle research.

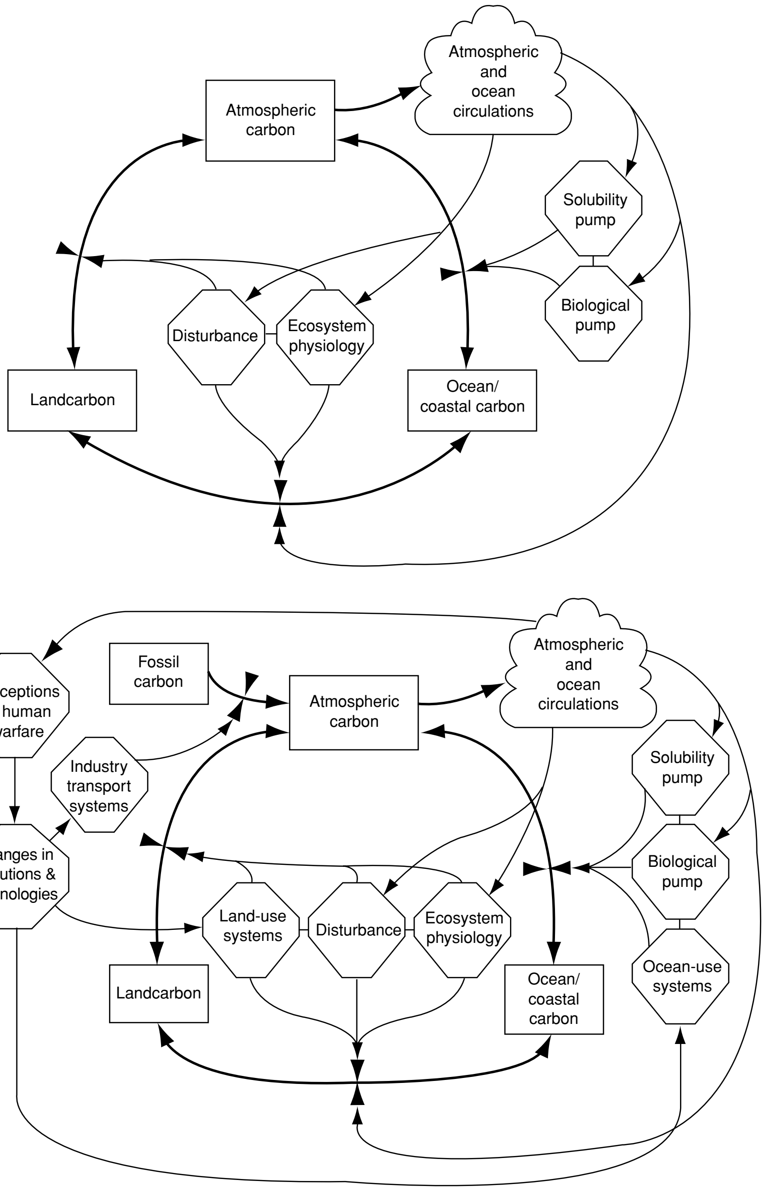


FIGURE 4 Two schematic representations of the carbon cycle. Figure 4a represents the carbon cycle before significant human activities influenced it and thus includes only biogeochemical processes. Figure 4b represents the carbon cycle including human interactions, which both alter the carbon cycle and respond to changes in it. Source: Hibbard et al. (2001).

> their activities are an integral part of the carbon cycle, and that the human-environment system is a single, highly linked and interactive system that drives the dynamics of the carbon cycle.

The contrast of approaches between the U.S. and international programs raised three questions that Rosa posed to the workshop:

- Why is there a fundamental difference between the two programs?
- Can the United States effort learn from other approaches?
- If the United States judges that integration of the natural and social sciences is inappropriate within its program, what will be the U.S. position in relation to the international program?

**Discussion**

Initial discussion focused on the first of Rosa's questions. Field said that the international project is different because it started later and that the U.S. program is now trying to engage the human dimensions community. Thomas Dietz cited the Carbon Cycle Working Group's request for this workshop as supporting evidence. Some participants nevertheless suggested that structural differences between the United States and European countries might make integrated analysis less likely here: they mentioned restrictions in agencies' missions, the lack of an environment ministry, and the absence of an influential Green party. Participants associated with the CCSP generally did not accept that there were structural problems. They noted an early mistaken belief on the part of agency officials responsible for organizing the CCSP that the needed social science research was ongoing in other programs, a lack of awareness of the need to connect the natural science and social science communities, and limited funding for social science research.

Ronald Mitchell noted the need for long-term time-series data on human activities—the social equivalent of ice core data—to learn how past human activities have altered the carbon cycle. For example, U.S. forest policy since 1776, including policies on fire suppression and road building in the 20th century, has affected carbon sinks. Time-series data on policies, treaties, and environmental outcomes should be collected. The discussion turned to whether social science had models that are well enough developed to use such data. Myron Gutmann claimed that proposals for historical research are sometimes rejected because they do not involve modeling.

He argued that data collection is needed first to make model building possible, just as geophysical models require measurements.

Discussion turned to the nature of the contribution social science could make. Field questioned how far down the chain of causation explanations should try to go beyond looking at the history of human activity. Jorge Sarmiento said that a historical viewpoint is important, but "we are past the warning phase" and into the phase of trying to find solutions. Mitchell countered that it is wrong to distinguish between studying history and finding solutions. History tells what the results of certain policies have been. It tells that proposed solutions often make matters worse and thus can help distinguish between promising solutions and those likely to be disappointing.

Emilio Moran noted the need for a long temporal record and the need to include archaeology. He also pointed out that social science rarely works at the global scale and suggested that the natural and social sciences might work best together at the regional scale. Field noted that the research tools in the natural sciences are now providing finer spatial resolution, which might make such collaboration easier.

Susan Stonich argued that the study of historical data needs to include people who know about history. She argued against simply entering numbers from the historical record into models.

Finally, the discussion touched on the difficulties of moving the research into new areas. There was disagreement about how easy it would be to expand carbon cycle research to include needed social science input. Thomas Wilbanks distinguished between the willingness to move into new areas and the ability of innovative proposals to succeed in review. He suggested that agencies needed to get the right balance of perspectives on review panels if they want research to move in new directions. Lisa Dilling concluded that the way to move this discussion forward is to focus on specific topics for which all the sciences are needed to make progress.

## THE FUTURE OF FOSSIL FUEL CONSUMPTION

### Economic Issues

Speaker: *Howard Gruenspecht, Resources for the Future*

Howard Gruenspecht began by noting that the "long run" in energy forecasts is about 20 years—far less than the 100-year forecasts desired in carbon cycle research. He discussed ways of analyzing energy use. At the first level is an accounting approach that decomposes energy use according to driving forces: level of activity, energy intensity of activity, and carbon intensity of energy. This analysis normally takes the form of an identity:

$$\text{Energy} = \text{Population} \times (\text{GDP/population}) \times (\text{energy/GDP}) \times (\text{carbon/energy})$$

in which the first two righthand terms represent economic activity, the third is energy intensity, and the last is carbon intensity. At a deeper level, economic activity is driven by capital formation and technology; energy intensity is affected by both energy production technology and energy use technology, as well as by distribution of income, which influences demand for energy services; carbon intensity is shaped by the relative prices of different fuel cycles given available technologies. Policy is a residual in the accounting equation, even though it obviously affects other terms in the equation.

Gruenspecht discussed the assumptions about the driving forces of carbon emissions that are embedded in the climate change scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). He noted that all the scenarios presume rapid increases in per capita income (10-25 times current levels by 2100) and that all presume a more even distribution of income across countries in the future than is now the case. The latter change, in particular, is not currently occurring. The scenarios also presume dramatic decreases in final energy intensity and in percentage of energy provided by coal, as well as increases in the percentage of energy from zero-carbon sources, although there are large disparities across the projections. Although the projections are claimed to reflect changes that would happen without policy interventions, Gruenspecht's view is that policies are embedded in them.

Gruenspecht compared these assumptions with the historical record in the United States. In the past 50 years, energy intensity decreased 50 percent; the IPCC scenarios suggest a fourfold decrease worldwide in the next 50 years. Electricity intensity has doubled in the United States. If that trend applies worldwide, electricity will become critical to the models and prices and policies related to electricity will matter a lot. Current projections suggest that fossil fuel supply constraints alone are unlikely to create price differentials sufficient to drive demand out of fossil fuels in the ways the scenarios project. Such an outcome will require either a major drop in the price of alternative energy sources or policy initiatives to reduce fossil fuel use. He noted that the real price of oil has remained within the range of $10-30/barrel in today's dollars for 140 years except for the period of 1973-1986. Decarbonization trends are continuing, but public opposition to nuclear and hydroelectric power raises questions about whether so-called autonomous declines in the carbon share of energy will continue indefinitely.

He concluded that the keys to whether the IPCC scenarios materialize are the development and penetration of technology and the future of policies that affect energy prices.

## Behavioral Issues

Speakers: *Chris Payne, Lawrence Berkeley Laboratory*
*Loren Lutzenhiser, Washington State University* (by telephone)

Chris Payne's research is on electricity use and energy conservation decision making, mainly using anthropological approaches. He noted the scientific debate about an "efficiency gap"—the difference between the behavior predicted by economic models of behavior and by technical models based on the level of efficiency that would be achieved if least-cost available technologies were fully in use. He noted that there is great variation in energy use when prices and technology are constant, indicating that people are also responding to other variables. Lifestyle variables, he argued, are important for understanding energy decision making. However, the best information on this topic is in the hands of marketers and is proprietary. Analysis requires better information and theory about lifestyle segmentation.

Loren Lutzenhiser noted that the social science resources applied to this problem have never been substantial and have thinned since the 1980s. In principle, though, social science analysis can unpack the concept of "affluence" or economic activity to reveal the roles of culture, social structure, settlement forms, past choices, and changes in these as a result of social movements, policies, and so forth.

He reported on preliminary results from data on the conservation response to the brief 2001 electricity crisis in California. Consumers cut usage 12 percent statewide from the previous year, which stabilized the situation without serious price effects. A total of 70 percent of households showed measurable declines in usage; however, 30 percent of that group, who saved an average of 35 percent, produced three-quarters of the aggregate savings. Lutzenhiser noted that 66 percent of a national Gallup poll sample in spring 2001 agreed that real changes in lifestyle would be necessary to protect the environment. The results were similar in California. The California results suggest that under some conditions, major lifestyle changes can be made quickly by a significant proportion of consumers. There is room for research on the potential for lifestyle changes to make a difference in fossil energy use.

## Commentary

Speaker: *Thomas J. Wilbanks, Oak Ridge National Laboratory*

Thomas Wilbanks argued that the future of fossil fuel use will reflect demand for energy services such as travel, heating and cooling buildings, and materials processing (reflecting a combination of need and ability to pay) and technological alternatives to fossil fuels (a function of ingenuity). Developing countries will drive demand: many analysts see the need to increase energy services three- to tenfold in these countries. The question is how to provide these services within environmental limits. To do this, there will need to be major increases in some combination of solar and nuclear energy supply, energy efficiency, and new energy technology. The IPCC scenarios do not, in his judgment, put the world on a path to a sustainable energy future.

Wilbanks noted two views about the effects of scenario building on human response. In one view, learning about the impacts of inaction will build pressure for action. In the other, learning about ways to adapt to climate change will reduce willingness to pay to avoid the impacts.

Wilbanks noted two elements of the knowledge base for projecting energy use. First, historical data can be used to project for about 20 years, and perhaps for 50 years in hypothetical ways, with some assumptions about prices. The relevant data are mostly descriptive and provide little information on developing countries. Second, research exists on energy use and energy responses in the 1970s, mostly from the United States and Western Europe. These data are quantitative but say nothing about how to promote the use of clean energy in developing countries.

Wilbanks argued for the need for research in four areas. First is the development of indicators useful for addressing current questions. In particular, there is a need for indicators of energy services that are separate from indicators of energy consumption. Second, there is a need for better understanding of conservation behavior, including the question of how much in the way of energy services is "enough" for people. Further discussion of this issue can be found in Kates (2000). Third, we need causal analyses of ways to increase the use of clean energy in ways that are socially and economically acceptable. Fourth, we need better understanding of the driving forces of energy use in developing countries.

## Discussion

Dietz began the discussion by noting that future emissions may be the largest source of uncertainty in climate scenarios and that the IPCC scenarios have no probabilities associated with them. He noted three relevant research traditions: economic analysis, technical analysis such as work on "decomposition" of emissions distributed at the workshop (Schipper et al., 2001; Price et al., 1999), and behavioral/social/lifestyle research.

M. Granger Morgan noted another type of research: on technologies for carbon separation and sequestration. He pointed out that all the technologies needed for taking carbon out of hydrocarbons are already in use at commercial scales, though for other purposes. He argued that in 10 years, the price for using them would be about the same as the price of wind energy today—that is, economically competitive. He noted that there are both technical questions and human dimensions issues, including public perceptions, related to the likelihood that sequestration technologies will be widely adopted. Also, he noted that if these technologies work, it will change the political economy of energy. Wilbanks noted that the search for sequestration technologies is prompted by the fact that current projections suggest unacceptable levels of carbon emissions.

Participants raised a variety of issues that might need investigation:

—the potential for relatively rapid lifestyle changes, such as the rapid declines in birth rates now occurring even in some of the poorest countries and the changes that often occur in times of crisis

—the effect of change in social institutions on energy use

—the claim that in the United States it is more politically feasible to change people's choice sets than to change their preferences or choices directly

—the counterclaim that policies have changed preferences (the example given was the rapid shift of the U.S. motor vehicle fleet toward sport utility vehicles, which were given lenient treatment by federal fuel economy standards policy)

—the need to use both observational and verbally elicited data to measure behavior

—the contribution of social science not only to estimating the means of behavior but their distributions, socially, spatially, and perhaps also temporally

—the need to take into account the continuing public opposition to nuclear power in many countries

—the need to consider policy options that now seem impossible, because they may not seem impossible in the future

—the role of private-sector organizations (e.g., insurance, agriculture, energy) that have interest in these issues and sometimes conduct research.

Mark Rosenzweig noted that the IPCC scenarios do not project the relationship between population and growth of gross domestic product (GDP). Endogenous growth theory, which has been developed in the past 10 years, shows that they are related. Rosenzweig claimed that theory rules out some of the IPCC scenarios as proposing impossible pairings of population and economic growth rates. He argued that carbon modelers must pay attention to endogenous growth models and link them to empirical data.

Sarmiento found it reassuring that social science might be able to rule out some scenarios and thus reduce the spread among their outputs. Moran argued that, to get social science integrated into analysis, it would help to look at an event of interest as a system, considering all the forces involved (climate, policy, etc.). Lutzenhiser noted that such an approach would also be helpful for the social sciences, which produce several models that do not interact adequately. A focus on a specific problem could lead to better understanding and shared vocabulary across disciplines.

## THE CARBON IMPLICATIONS OF FUTURE LAND COVER/ LAND USE TRANSFORMATIONS

### A Carbon Cycle Modeling Perspective

Speaker: *Ruth DeFries, University of Maryland*

Ruth DeFries noted that land use transformations were the main anthropogenic perturbation of the carbon cycle until the 20th century. Tropical deforestation, of such great concern at present, is only a relatively recent part of the history. The accounting is complex: in the 1980s, it is believed that carbon emissions from fossil fuels were $5.5 \pm 0.5$ Gt/yr. From land use, emissions were $1.7 \pm 0.8$ Gt/yr, and the uncertainty may be even greater than that estimate indicates. The "missing" carbon sink was estimated to be $1.9 \pm 1.3$ Gt/yr, much of it on land.

The importance of these estimates and uncertainties lies in two facts: that different mechanisms for the sink have different implications for the future and that most of the mechanisms of sinks have a large component involving land management (not just land cover). These points underscore the need to address the following human dimensions issues:

- understanding patterns and processes of land use change as they affect net emissions
- understanding the legacies of past land management for the current terrestrial sink
- projecting future land use patterns, including consideration of surprises.

DeFries argued that it is possible to do better than extrapolating from the past. By addressing the above questions, it is possible to analyze whether the IPCC estimate is realistic that 1 Gt/yr of carbon can be sequestered through changes in land management by 2010. To link human dimensions research on land use to carbon cycle research, DeFries argued that it is important to move from the pattern of changes in the carbon sink to the underlying processes and then to consider the pattern in light of the processes. She noted that social science normally works at smaller scales than the global and that the linkage is probably best accomplished at the regional scale.

## A Human Dimensions Perspective

Speaker: *Emilio Moran, Indiana University*

Emilio Moran began by noting the links between carbon cycle research and the existing international Land Use/Land Cover Change (LUCC) and Past Global Changes (PAGES) research programs, which are reconstructing the history of land use/land cover change over the past 300 and 6,000 years. These projects link the social and natural sciences, and the involvement of social scientists in the long-term ecological research sites is also promising. A new international program on Human Impacts on Terrestrial Ecosystems (HITE) promises to improve the linkages further. Although these programs are relevant to the carbon cycle, the documents of the LUCC program, for one, rarely mention carbon explicitly.

To integrate the natural and social sciences, Moran said, scientists need to agree on the value of regional modeling and also to examine the household level of analysis. It is also necessary to consider both industrial and land-based carbon sources. In addition, it is important to standardize land cover classifications. Progress is being made by comparing household-level data with remote observations, although at present, such comparisons show 30-50 percent errors in the estimates made from remote observation alone. A related issue is the storage of carbon below ground, which is greater in the tropics than is sometimes believed, although it varies considerably across sites. A land classification system is being developed that works fairly well. The next step is to move from classification toward a continuous-measurement approach.

Researchers are using spatially explicit models at increasingly regional levels. There is still a gap between the historical reconstructions and models. This might be closed by using agent-based models, which include learning and adaptation.

Progress is being made by comparing multiple case studies. A searchable database of 1,000 case studies has been prepared. One project is examining 142 case studies of tropical deforestation to look at the driving forces. It finds that although population growth accounts for some of the change, cultural expansion and other factors are more important. Similar analyses can be done for agricultural intensification, desertification, and urbanization. Research has progressed to the point that additional case studies should be funded only if they are connected to larger analytical efforts.

The future development of LUCC, Moran said, should be to move measurements farther into the past and to develop structured case comparisons in a few localities involving integrated science.

## Commentary

Speaker: *Mark Rosenzweig, University of Pennsylvania*

Mark Rosenzweig noted that current information about land cover and land cover change is not very good. In many cases, government data are created from assumptions about population and land cover change;

analyses of such data will reveal the agency's assumptions rather than phenomena on the ground. For instance, forest cover data on India since the 1970s is based on land set aside for forests. Remote sensing data indicate that tree growth has lagged behind official estimates. Forest cover in India has nevertheless increased while population has also grown, because of changes in land management.

Rosenzweig said that social science can make contributions to interdisciplinary analysis by increasing concern about the quality of data used in analysis and by analyzing land management as behavior—an outcome of private decisions and public policies. However, for it to make its best contributions, it will be necessary to greatly reduce the price of satellite data to researchers.

## Discussion

Some of the discussion focused on the definition of "region." Some of the social scientists said that a region could be a landscape, a watershed, a county, a state, or some other unit, depending on the purpose of the study. There is no ideal scale for every purpose. DeFries said that regions could be defined by similarities in processes (more similar within than between regions). Dietz noted that analyses of local phenomena should also take into account that these are influenced by phenomena at larger scales.

There was also discussion of issues of scale. Barbara Entwisle noted that reasoning from case studies requires both general principles and specific knowledge, as with treating medical patients. Agent-based modeling has the potential for moving from cases up to the big picture by modeling how individual behaviors interact. She also emphasized that scale is not only spatial, but also temporal, and social (that is, a function of the purviews of different forms of social organization). Carbon cycle modelers typically work at larger scales on spatial, temporal, and social dimensions than most social scientists. Wilbanks noted the importance of understanding interactions across scales and mentioned that there are methods for doing this, such as patch dynamics in ecology. Mitchell noted that the scales of human decision making do not neatly match those of environmental impacts. An aquifer may be affected by actions of various organizations and units of government with overlapping jurisdictions.

John Houghton said that what the agencies need most is a short list of topics to pose to the research community. A few suggestions came immediately from the participants:

—How can remote sensing be used to give useful data on tillage?

—What have been the effects of land use policy across space and time (the idea of a video of land change, showing policy effects)?

—There is evidence that creating reserves sometimes makes matters worse by attracting attention to the resources in the reserve. Is this a general phenomenon?

## MODELING HUMAN INTERACTIONS WITH THE CARBON CYCLE

### A View from a Carbon Cycle Modeler

Speaker: *Jorge Sarmiento, Princeton University*

Jorge Sarmiento described carbon cycle modelers as doing four things: (1) reconstructing historical carbon sources and sinks, (2) predicting carbon dioxide concentrations given emissions, (3) predicting emissions given target carbon dioxide concentrations (i.e., defining emissions trajectories that would yield target carbon dioxide levels), and (4) evaluating sequestration scenarios. In this context, one way that human dimensions can be involved is in relation to the human implications of arriving at some target carbon dioxide concentration.

Modelers have modeled past carbon data and projected the models into the future. They have found that the uncertainties in future emissions are much greater than the uncertainties in the natural science of the carbon cycle; uncertainties about carbon sinks are also important. As an example of the importance of sink uncertainties, Sarmiento showed two simulations with emissions scenarios similar to the IPCC IS92a scenario using fully coupled models covering land, oceans, and atmosphere. The scenarios resulted in $CO_2$ concentrations of between 400 and 700 ppm in 2100, with differences depending on the effects of warming on the land sink. The scenarios also varied 2.5 degrees C in average temperature over land.

Modelers have also calculated possible emissions trajectories to target $CO_2$ concentrations of 450, 550, and 750 ppm based on current estimates of the land and ocean sinks. This kind of simulation depends on the ability to estimate the sinks accurately.

Sequestration is also analyzed with scenarios—for example, a sequestration scenario might assume that enough $CO_2$ is emitted to yield a stable concentration of 750 ppm, but enough of it is sequestered so that the actual stable concentration is 450 ppm. Such analysis works backward to estimate how reservoirs can be leaky and still meet the desired concentration target. This kind of analysis calls attention to the problem of how much of this carbon could actually be sequestered under realistic conditions.

What carbon cycle modelers need for model development is a reconstruction of historical emissions and land use change. What they need for warning purposes is the development of good scenarios. What they need for informing policy solutions is scenarios leading to stabilization of $CO_2$ concentrations. Sarmiento concluded by distinguishing three approaches to assessment: an optimization framework based on economics and often not including ecology, an ecosystem approach based on assessing possible damages to ecology but without economics, and an approach focused on avoiding catastrophe. The latter two approaches identify tolerable windows and safe corridors in terms of emissions and make it possible to take an approach in which scientists warn and society adjusts. Using this approach needs as much accuracy as possible in developing the assessments.

## A View from Human Dimensions Research

Speaker: *Hugh Pitcher, Joint Global Change Research Institute*

Hugh Pitcher emphasized the need to look at look at the entire system (going beyond carbon) and to recognize the importance of uncertainty and the likelihood that scenarios will evolve. For example, he noted that if nitrogen oxide emissions are reduced, this will alter the carbon fertilization effect. He emphasized the need to improve qualitative understanding of the links among subsystems such as these.

Regarding uncertainty, Pitcher argued that we don't know what we don't know well enough to do anything like optimization. For example, the temperature outcome of human activity depends on both the size of the carbon sink and the climate sensitivity to carbon concentrations, both of which are unknown.

Pitcher discussed the evolution of the IPCC emissions scenarios (Working Group III, 2000). The newer population scenarios have revised fertility estimates to reflect more recent data, but some of the scenarios still have fertility estimates that are too high. Pitcher said that the life expectancy estimates are too optimistic—that it will not improve as much or as fast as the scenarios assume. Also, changes in population growth rates will change age structures in ways that have effects on society. The models need to include intelligent agents who make adjustments. He suggested that the scenarios could be subjected to scrutiny by social scientists and that it may be necessary to revisit several issues related to population estimation.

Pitcher also commented on other aspects of the scenarios. He suggested that development is much more difficult than many of the scenarios suggest. The development scenarios also raise the question of how food and energy demand may change with unprecedented levels of income. He commented that the land use effects on the emissions scenarios are not really understood yet and that the mitigation scenarios all involve mitigation only of $CO_2$. Pitcher concluded that because we do not yet know what we don't know, it is important to use the scenarios framework as a way of explaining our ignorance.

## Discussion

Stephen Schneider opened the discussion by raising the issue of the likelihoods of the various scenarios. He agreed with Pitcher that it is worthwhile to examine the population scenarios, noting that doing this would help clarify the relative likelihoods of the scenarios. He argued strongly for efforts by scientists to estimate how likely the various scenarios are because if they do not, scenario users would do the estimating, and this would be much more dangerous.

Other discussion focused on the accuracy and realism of the scenarios. Morgan noted that the population and GDP scenarios both showed variation of about a factor of 2 and asked whether that meant equal certainty about the two parameters. Pitcher replied that he thought the population estimates were about right but that the GDP scenarios were probably optimistic. He said the scenario exercise did not explore slow-growth scenarios. Nevertheless, he did not think the variances should be wider than those used—unless there is a big surprise from an infectious disease.

Gutmann questioned the age structures implied by the demographic scenarios. He believed that if the projected age structure started to materialize, people would adjust by increasing birth rates. He asked whether the age structures implied by the scenarios have ever existed and doubted that they could possibly last as long as projected. Pitcher noted that the models lack economic and demographic feedbacks.

Morgan suggested that there is a structural limitation to the scenarios that an intergovernmental process such as IPCC would consider. They will not do catastrophe scenarios, and probably also will not do scenarios involving lack of economic development. He proposed that scenarios be developed independently of intergovernmental processes so that plausible but politically unappealing scenarios can be explored. Pitcher noted that the IPCC scenario exercise cost $5-10 million. He suggested that it would be better to have independent assessments and to let the IPCC select some of them to use.

Other speakers raised other possible problems with the models. Steven Shafer noted the importance of tropospheric ozone to agriculture. Granville Sewell suggested simulating changes in the climate change regime—for example, simulating what would happen if the Clean Development Mechanism turned out to be only a system of trading credits among wealthy countries. Rosenzweig supported the suggestion that more attention needs to be given to the scenarios regarding their assumptions about demography, economics, and their interaction. He also raised a question about assumptions about international trade: high rates of development will change trade and also the composition of goods consumed. In addition, he argued that trade will feed back to influence changes in income distribution. Pitcher noted that the models do not account at all for such interactions. He added that it is hard to believe the models more than 50 years out because of lack of understanding of the underlying processes.

## CLOSING DISCUSSION: NEXT STEPS

### Commentary

Speaker: *Edward Parson, Harvard University*

Edward Parson said that the most interesting points flow from the fact that changes in emissions due to energy use and land use predominate over all other sources of uncertainty in the scenarios. This implies that there is a need to project human history. It is necessary to ask which futures are plausible, how policy interventions change the system, how robust the relationships are, and so forth.

He noted that these questions look like futurism, not research. They are therefore hard to defend and fund, and social scientists are uneasy about them, for both good and bad reasons. Parson argued that with theory and evidence, models can be specified, but he noted that many social scientists have a distaste for practical application and also that the ability to explain and predict is weak.

This situation creates a difficult problem. It is necessary to understand the past and present across situations and times, but it is not necessary to understand everything to make a contribution to projections and to policy. It is therefore important to identify the insights that might come from information on the past that map onto future needs. It is also important to consider whether generalizations from the past will continue to hold in a future that contains some unprecedented conditions.

Parson suggested the following topics for attention:

1. Examine existing scenarios and models to identify the important questions. We have heard specialists who are critical of parts of the models. The people who know the processes in detail must be engaged to help identify the important issues.

2. Use models to elaborate uncertainties. Uncertainties should be structured in various ways, including speculation to identify them. Analyses could also start at the back end to ask whether particular physical end points are socially and economically feasible.

3. Investigate issues about which not enough is known. Parson noted two: one is the sources of "endogenous" technological changes that affect carbon and climate, particularly the specific character of those changes. The other is the conditions that make a threat salient enough to bring about major social changes. For example, the terrorist attacks on September 11, 2001, seem to have reversed a decades-long decline in trust of government.

4. Improve data on the human dimensions. We need comparative and historical socioeconomic data on states and trends of human activities that affect the carbon cycle, leading to an atlas that records human behavior at a fine spatial scale. For example, remotely sensed data can probably be mined for more indicators of important human activities such as energy conversion.

5. Explore the implications of alternative policies and technological changes.

### Commentary

Speaker: *Christopher Field, Carnegie Institution of Washington*

Field noted that there is broad appreciation that the natural sciences and the social sciences need each other: you can't do good science using scenarios without understanding the human dimensions issues. Even the current carbon budget, he noted, is driven primarily by human interactions. He suggested that progress can be made by focusing on concrete initiatives, and noted three possibilities:

1. Improve simulations to build better understanding of uncertainties
2. Address issues of scale and the history of the carbon cycle by combining remotely sensed data, resource inventories, and other data sources
3. Make future emissions scenarios meaningful by incorporating an appropriate set of economic and institutional drivers and the research that can improve understanding of these relationships.

Field concluded by noting that oceanography and astronomy, which both need expensive assets to do their research, have gained support for those assets by developing consensus research agendas for a big question. Individual researchers then gain support by relating their research to that question.

### Commentary

Speaker: *Lisa Dilling, National Oceanic and Atmospheric Administration*

Dilling identified three issues of interest to both communities:

1. Understanding the mechanisms leading to changes in the carbon cycle. Doing this requires knowledge of historical and current conditions, as well as past policies. Both communities are needed to develop this understanding.
2. Developing more accurate projections. Scenarios are used for this, and Dilling suggested that natural science scenarios are needed, as well as social science ones.
3. Developing solutions. This is a gray area between science and policy and includes analysis of sequestration options as well as institutional and behavioral changes.

Dilling concluded that integration is the big challenge and suggested that the way to proceed is by picking specific topics. She mentioned the need to address issues of scale and to identify critical data needs. She called on the participants to identify priority topics.

## Discussion

Participants were invited to write down topics they believed deserved the most immediate attention, and some of them submitted suggestions. The suggestions, in abbreviated form, were posted at the front of the room as a stimulus for discussion.

Several of the written suggestions involved collecting and analyzing historical records to improve understanding of human influences on the carbon cycle. The most general suggestion of this type was to quantify the past trajectory of carbon sources and sinks in terms of social drivers (economics, policies, institutions) as well as biogeophysical drivers. Two more specific suggestions involved studying the history of land use/land cover change in particular regions with attention to periods of significant change. There was particular interest in North America, where the contemporary terrestrial carbon sinks are the consequence of past net emissions. One participant noted that the same sequence may occur in the tropics in the future. Another suggestion was to analyze important moments of change in human interaction with the carbon cycle to identify the actions that produced the change and trace the longer-term effects (the example was fossil fuel use after 1973 and subsequent improvements and declines in the fuel efficiency of motor vehicles).

Some suggestions involved analyses of policies and their effects. A participant suggested that carbon cycle studies collect and analyze data on policies and institutions that have intentionally or unintentionally affected the behaviors that drive human contributions to the carbon cycle by altering technology, lifestyle, or other aspects of human life. Another suggested specific historical studies of the carbon implications of designating reserves or protected areas.

A variety of suggestions focused on the modeling and scenario-building processes. One participant suggested developing a set of meaningful carbon emission scenarios that include a rich set of economic, policy, technology, and institutional contexts, including sensitivity to climate. Another suggested building scenarios that begin with policy objectives and work backward. Another suggested directing research attention to areas in which models are most dependent on "backfilling" (i.e., estimated data rather than actual measurements) and uncertainties matter most. Other participants suggested the need for models to do more to include analyses of technological change processes and to incorporate macroeconomic analysis. One suggested more work comparing top-down and bottom-up studies of the carbon budget. Another emphasized the need to improve the capability of integrated assessment analysis to incorporate multi-scale interactions. Finally, one participant suggested using case studies to build case-specific land-use/land cover scenarios and using those scenarios to bound assumptions about land change in global models and to test the sensitivity of model outputs to assumptions about land change.

Other written suggestions were difficult to classify. One participant suggested the need for regionally based studies of how people make land use or energy use decisions. Another suggested more attention to learning by doing—to how people and social systems improve their responses to environmental challenges over time. Yet another, noting that the appropriate scale of analysis is contingent on the research question, suggested a need to map basic research and policy questions to appropriate scale. For example, population may be a key driver of carbon dynamics at the global level, while this may be less true at the regional level. It would be useful to sketch these issues and develop a framework for integrating different scales.

In the open discussion, demographic variables received considerable attention. It was claimed that a large set of data in demography had not been used in carbon cycle modeling and that the models use population data in ways that do not reflect the state of the art. Moran suggested that at least one of the carbon modeling groups establish links with one of the population research centers to bring in expertise on population dynamics. Eric Sundquist agreed, noting that the U.S. Geological Survey and the Census Bureau are working together to reconstruct data on the history of population and farm land in the United States by county. There have been problems making these data publicly available.

Another topic was data quality and the issue of backfilled data that are calculated from other information, with considerable uncertainty. It was suggested that the backfilled data be presented with uncertainty bounds or at least be flagged as potentially bad data. This would make it possible for future research to improve the data used in models.

There was discussion of add-ons—additions of money to funded research projects for additional tasks on the sponsor's priority list—as an option distinct from new funding initiatives. An example offered was a study of fossil fuel use that might be asked to add on data on changing speed limit policies so the policy effects could be analyzed. Participants disagreed about the potential value of add-ons. An argument in favor was that it could leverage funds; an argument in opposition was that some social scientists had resisted environmental add-ons in past National Science Foundation funding rounds.

Other suggestions for supporting integration of social and natural science expertise were to require cross-disciplinary collaboration as a condition for funding as some programs of the Environmental Protection Agency have done and to add money to multiple projects for cross-project meetings if the sponsoring agency sees benefit in bringing them together.

Sarmiento saw a need for a social science equivalent of the scientific detection and attribution research that has been done on global climate change. He also raised the question of research on carbon management. Dietz said that such research could investigate both whether a particular management goal is attainable and what it would take to achieve it. Sally Kane noted a need for research on adaptation as well as management. Pitcher noted that none of the existing environmental control models include the cost of management choices and suggested that consistent pricing elements need to be incorporated into models.

Schneider noted institutional constraints and opportunities in doing this kind of work and raised a few substantive issues. If leakage of sequestered carbon is a critical issue, he proposed research on "learning by doing" and on how to reduce leakage by learning. He suggested research on the internal consistency of scenarios as a way to move toward attaching probabilities to the scenarios. This suggestion ties to discussions earlier in the workshop about having scenarios developed separately from the process of assessing them and about "forbidden" questions in scenario development (such as "What happens if development lags in many developing countries?"). Schneider also proposed research on the inertial effects of human activity past 2100, because that is when the most serious climate changes appear most likely to occur.

Dilling concluded the workshop by saying that it had been very helpful to the Carbon Cycle Working Group. Houghton asked that the specific suggestions be forwarded to the agencies, with additional detail.

# References

Gupta, G., L. Lebel, P. Vellinga, O. Young, and the IHDP Secretariat

2001 *IHDP Global Carbon Cycle Research: International Carbon Research Framework.* Bonn, Germany: International Human Dimensions Programme on Global Environmental Change.

Hibbard, K., W. Steffen, S. Benedict, T. Busalachi, P. Canadell, R. Dickinson, M. Raupach, B. Smith, B. Tilbrook, P. Vellinga, and O. Young

2001 *The Carbon Challenge: An IGBP-IHDP-WCRP Project.* Stockholm: International Geosphere-Biosphere Programme.

Kates, R.

2000 Population and consumption: What we know, what we need to know. *Environment* 42(3):10-19.

National Research Council

1992 *Global Environmental Change: Understanding the Human Dimensions,* Committee on the Human Dimensions of Global Change, P.C. Stern, O.R. Young, and D. Druckman, eds. Washington, DC: National Academy Press.

Petit, J.R., J. Jouzel, D. Raynaud, N.I. Barkov, J.M. Barnola, I. Basile, M. Bender, J. Chappellaz, M. Davis, G. Delaygue, M. Delmotte, V.M. Kotlyakov, M. Legrand, V.Y. Lipenkov, C. Lorius, L. Pepin, C. Ritz, E. Saltzman, and M. Stievenard

1999 Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature* 399:429-436.

Prentice, I.C., G.D. Farquhar, M.J.R. Fasham, M.L. Goulden, M. Heimann, V.J. Jaramillo, H.S. Kheshgi, C. Le Quéré, R.J. Scholes, and D.W.R. Wallace

2001 The carbon cycle and atmospheric carbon dioxide. P. 944 in *The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, and D. Xiaosu, eds. Cambridge, Eng./New York: Intergovernmental Panel on Climate Change.

Price, L., E. Worrell, and M. Khrushch
1999 Sector Trends and Driving Forces of Global Energy Use and Greenhouse Gas Emissions: Focus on Industry and Buildings. Unpublished manuscript, Lawrence Berkeley National Laboratory, Berkeley, CA.

Sarmiento, J.L, and S.C. Wofsy, co-chairs
1999 *A U.S. Carbon Cycle Science Plan.* Washington, DC: U.S. Global Change Research Program.

Schipper, L., F. Unander, S. Murtishaw, and M. Ting
2001 Indicators of energy use and carbon emissions: Explaining the energy economy link. *Annual Review of Energy and the Environment* 26:49-81.

Subcommittee on Global Change Research
2001 *Our Changing Planet: The FY 2002 U.S. Global Change Research Program.* Washington, DC: Subcommittee on Global Change Research, Committee on Environment and Natural Resources, National Science and Technology Council.

Working Group I, Intergovernmental Panel on Climate Change
2001 *Summary for Policymakers.* Geneva, Switzerland: Intergovernmental Panel on Climate Change. [Online]. http://www.ipcc.ch/pub/spm22-01.pdf. [Accessed: 3/1/02].

Working Group III, Intergovernmental Panel on Climate Change
2000 *Emissions Scenarios: Summary for Policymakers.* Intergovernmental Panel on Climate Change.

# Appendix

# Workshop on Human Interactions with the Carbon Cycle

**AGENDA**

**November 5, 2001**

| | |
|---|---|
| 8:00 am | Continental breakfast in meeting room |
| 8:30 am | Opening remarks—Thomas Dietz, committee chair |

**Human Dimensions in National and International Carbon Cycle Research**

| | |
|---|---|
| 8:45 am | Human dimensions in the U.S. carbon cycle research program—Chris Field, Stanford University |
| 9:00 am | Human dimensions in the international carbon cycle research program—Eugene Rosa, Washington State University |
| 9:15 am | Discussion |

**Human Activities Driving the Carbon Cycle**

*The future of fossil fuel consumption*

| | |
|---|---|
| 9:45 am | Economic issues—Howard Gruenspecht, Resources for the Future |
| 10:00 am | Behavioral issues—Chris Payne, Lawrence Berkeley Laboratory, and Loren Lutzenhiser, Washington State University |
| 10:15 am | Commentary—Thomas Wilbanks, Oak Ridge National Laboratory |
| 10:30 am | Discussion |

*The carbon implications of future land cover/land use transformations*

| | |
|---|---|
| 11:15 am | A carbon cycle modeling perspective—Ruth DeFries, University of Maryland |
| 11:30 am | A human dimensions perspective—Emilio Moran, Indiana University |
| 11:45 am | Commentary—Mark Rosenzweig, University of Pennsylvania |
| 12:00 | Discussion |
| 12:30 pm | Lunch |

**Modeling Human Interactions with the Carbon Cycle**

*What carbon cycle modelers need from human dimensions research*

| | |
|---|---|
| 1:00 pm | A view from a carbon cycle modeler—Jorge Sarmiento, Princeton University |

1:15 pm A view from human dimensions research—Hugh Pitcher, Pacific Northwest Laboratory

1:30 pm Commentary—Stephen Schneider, Stanford University

1:45 pm Discussion

2:15 pm **Closing Discussion: Next Steps**
Comments
Ted Parson, Harvard University
Chris Field, Stanford University
Lisa Dilling, National Oceanic and Atmospheric Administration

2:30 pm Open discussion

3:00 pm Adjourn workshop

## WORKSHOP PARTICIPANTS

Krisa Arzayus, Office of Global Programs, National Oceanic and Atmospheric Administration
Mitchell T. Baer, Office of Policy and International Affairs, U.S. Department of Energy
Nancy Beller-Simms, Office of Global Programs, National Oceanic and Atmospheric Administration
Jeri L. Berc, Natural Resources Conservation Service, U.S. Department of Agriculture
Ruth DeFries, Department of Geography and Earth System Science Interdisciplinary Center, University of Maryland
*Thomas Dietz, Department of Environmental Science and Policy and Department of Sociology and Anthropology, George Mason University
Lisa Dilling, Office of Global Programs, National Oceanic and Atmospheric Administration

* Member, Committee on the Human Dimensions of Global Change

*Barbara Entwisle, Department of Sociology, University of North Carolina, Chapel Hill
Christopher Field, Carnegie Institution of Washington, Stanford, CA
Howard Gruenspecht, Resources for the Future, Washington, DC
*Myron Gutmann, Inter-University Consortium for Political and Social Research, University of Michigan
Cliff Hickman, Forest Service, U.S. Department of Agriculture
John C. Houghton, Office of Biological and Environmental Research, U.S. Department of Energy
Carol Jones, Economic Research Service, U.S. Department of Agriculture
Sally Kane, Office of Global Programs, National Oceanic and Atmospheric Administration
Loren Lutzenhiser, Department of Sociology, Washington State University
Beverly Mcintyre, Office of Global Change, U.S. Department of State
Frederick A.B. Meyerson, AAAS/NSF Science and Technology Policy Fellow, National Science Foundation
*Ronald Mitchell, Institute for International Studies, Stanford University
Kenneth Mooney, Office of Global Programs, National Oceanic and Atmospheric Administration
*Emilio Moran, Department of Anthropology, Indiana University
*M. Granger Morgan, Department of Engineering and Public Policy, Carnegie Mellon University
Claudia Nierenburg, Office of Global Programs, National Oceanic and Atmospheric Administration
Jessica Orrego, Office of the U.S. Global Change Research Program
*Edward Parson, Environment and Natural Resources Program, John F. Kennedy School of Government, Harvard University
Chris Payne, Lawrence Berkeley Laboratory, Washington, DC
Hugh Pitcher, Joint Global Change Research Institute, College Park, MD
Donald L. Rice, Chemical Oceanography Program, National Science Foundation
*Peter Richerson, Division of Environmental Studies, University of California, Davis
Eugene Rosa, Department of Sociology, Washington State University
*Mark Rosenzweig, Department of Economics, University of Pennsylvania
Jane Ross, Center for Social and Economic Studies, National Research Council

Jorge Sarmiento, Atmospheric and Oceanic Sciences Program, Princeton University

Stephen Schneider, Stanford University

Peter Schultz, Koshland Science Museum, National Research Council

Granville C. Sewell, Institutional Dimensions of Global Environmental Change Program Office and Stratus Consulting, Inc., Washington, DC

Steven R. Shafer, Agricultural Research Service, U.S. Department of Agriculture

Caitlin Simpson, Office of Global Programs, National Oceanic and Atmospheric Administration

Paul C. Stern, Committee on the Human Dimensions of Global Change, National Research Council

*Susan Stonich, Department of Anthropology, University of California, Santa Barbara

Eric Sundquist, U.S. Geological Survey, Woods Hole, MA

Barbara Boyle Torrey, Division of Behavioral and Social Sciences and Education, National Research Council

*Elke Weber, Department of Psychology, Columbia University

Diane E. Wickland, Terrestrial Ecology Program, National Aeronautics and Space Administration

*Thomas J. Wilbanks, Oak Ridge National Laboratory, Oak Ridge, TN