United States
Environmental Protection
Agency

Office of the Administrator
Science Advisory Board
Washington, DC 20460

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EPA

# Report of the Global Climate Change Subcommittee

# Review of the Report to Congress:

# Policy Options for Stabilizing Global Climate

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D C. 20460

OFFICE OF
THE ADMINISTRATOR

September 15, 1989

The Honorable William K. Reilly
Administrator
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, DC 20460

RE: Policy Options for
Stabilizing Global Climate

Dear Mr. Reilly:

We are pleased to transmit via this letter the report of the Science Advisory Board's Global Climate Change Subcommittee concerning their review of the Agency's second report to Congress on Global Climate Change. This draft report, Policy Options for Stabilizing Global Climate, was reviewed by the Subcommittee on April 4-5, 1989 with comments offered directly to EPA staff.

The Subcommittee commends EPA for its portrayal of policy options for stabilizing global climate. Our overall reaction to the draft Stabilizing Report is generally positive. This report represents, to our knowledge, the most comprehensive effort to date to deal with the full range of radiatively active or greenhouse gases (carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, ozone) over a time period extending out to the year 2100.

The publication of this report is timely, with the United States in the position to provide leadership in defining and implementing policy options that can contribute to stabilizing global climate. The analysis in the Stabilizing Report indicates that some of the most important aspects of these options can be foreseen now, even though many important uncertainties remain, both in the scientific understanding of the extent and character of global climate change, and in the problems and promise of the policy opportunities. With appropriate revisions, we believe that the report will contribute significantly toward increased understanding of the character and magnitude of the task of setting policies to stabilize global climate.

We appreciate the opportunity to provide our comments on this important national and international environmental problem.

Sincerely,

D. Warner North
Chairman
Global Climate Change
Subcommittee
Science Advisory Board

Raymond C. Loehr
Chairman
Executive Committee
Science Advisory Board

ABSTRACT

This report presents the views of the U.S. Environmental Protection Agency's Science Advisory Board concerning its review of the EPA's draft report to Congress entitled: "Policy Options for Stabilizing Global Climate". The Board commends EPA for its portrayal of policy options for stabilizing global climate. The draft Stabilizing Report represents, to the Board's knowledge, the most comprehensive effort to date to deal with the full range of radiatively active or greenhouse gases (carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, ozone) over a time period extending out to the year 2100. This report provides worldwide projections of the emissions of these gases under plausible future scenarios and examines the effects of policy options in reducing emissions levels. Some of the most important aspects of these options can be foreseen now, even though many important uncertainties remain, both in the scientific understanding of the extent and character of global climate change, and in the problems and promise of the policy opportunities. With appropriate revisions, the Board believes that the report will contribute significantly toward increased understanding of the character and magnitude of the task of developing policy options to stabilize global climate. Furthermore, the Board believes that assessment of the potential effects of global climate change, the evaluation of stabilizing options, and the research on climate change, effects, technologies that may reduce emission rates, and on the institutional and implementation issues in deploying these technologies should all be pursued immediately and vigorously as part of a coordinated program, within EPA, the Federal Government, and through international organizations.

Key Words: Greenhouse Gas; Global Climate Change; Policy Options

NOTICE

This report has been written as part of the activities of the Science Advisory Board, a public advisory group providing extramural scientific information and advice to the Administrator and other officials of the U.S. Environmental Protection Agency. The Board is structured to provide a balanced expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency; and, hence, the contents of this report do not necessarily represent the views and policies of the Environmental Protection Agency or other agencies in the Federal Government. Mention of trade names or commercial products does not constitute a recommendation for use.

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## 1.0 EXECUTIVE SUMMARY

The United States Environmental Protection Agency (EPA) has been asked by Congress to report on the potential environmental and health effects of global climate change and the choices the global community may need to consider in order to limit and adapt to potential global warming. The two reports that EPA is preparing in response to this request are the Potential Effects of Global Climate Change on the United States and Policy Options for Stabilizing Global Climate. The EPA has asked its Science Advisory Board (SAB) to establish a review panel to evaluate these reports.

The SAB established the Global Climate Change Subcommittee with the charge to review these two reports in draft form and evaluate their technical adequacy, uncertainties, and consistency of recommendations with the findings contained in the reports. The EPA plans to incorporate SAB comments in their revision of the two reports before they are finalized and transmitted to Congress. The SAB report on the first document, Potential Effects of Global Climate Change on the United States was released in April 1989 (See U.S. EPA Report, EPA-SAB-EC-89-016, April 1989). The present SAB report presents the conclusions and recommendations of the Subcommittee on its review of the second report, Policy Options for Stabilizing Global Climate (known hereinafter as the Stabilizing Report).

The Subcommittee commends EPA for its portrayal of policy options for stabilizing global climate. Our overall reaction to the draft stabilizing report and the presentations made to the Subcommittee on April 4-5, 1989 are generally positive. This report represents, to our knowledge, the most comprehensive effort to date to deal with the full range of radiatively active or greenhouse gases (carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, ozone) over a time period extending out to the year 2100. The report provides worldwide projections of the emissions of these gases under plausible future scenarios and examines the effects of policy options in reducing emissions levels. Major weaknesses of the draft report lie in Chapters VIII and IX, which focus rather narrowly on near-term options to reduce energy demand, with relatively minimal discussions of research and development and opportunities for United States leadership through international cooperation; and the failure of the report to provide sufficient information on the costs or possible trade-offs involved

in choosing between and implementing various stabilizing options. With appropriate revisions, we believe that the report will contribute significantly toward increased understanding of the character and magnitude of the task of setting policies to stabilize global climate.

The draft Stabilizing Report summarizes calculations indicating that a reduction of at least 50% from today's rate of worldwide emissions of carbon dioxide and substantial reductions in emission rates for other greenhouse gases are needed to stabilize the concentrations of these gases at their current levels in the atmosphere (Executive Summary, Figure 4, p. 14; Table 1, p. 15). The draft Stabilizing Report states that such large reductions in emissions are judged to be infeasible (Executive Summary, p. 86):

> Stabilizing the commitment to global warming would require cuts in emissions so significant that currently available and emerging technologies are insufficient to achieve this goal.

The report, therefore, examines policies that could stabilize the rate of emissions, rather than atmospheric concentrations of the radiatively important gases at levels roughly comparable to those prevailing today, under scenarios that reflect plausible estimates of world population growth and economic development through the next century. The policies are intended to stabilize global climate at an altered level of radiative balance, corresponding to an increase in realized global average temperature of one or two degrees Celsius by the year 2100 and a long-term equilibrium commitment to a global average warming somewhat higher, in the range of 1.4 to 3.3°C (Appendix B, Table B-152, B-153). The report notes that an equilibrium warming commitment of 0.7 to 1.5°C relative to the preindustrial era is expected due to emissions up to the present time, and that continued emissions during the next several decades at projected levels could lead to an equilibrium warming commitment in the range of 1 to 3°C.

The analysis presented in the report uses realized global average temperature over time and long-term equilibrium commitment to global average warming as indicators to describe the magnitude of global climate change. (The long-term equilibrium warming commitment is the amount of warming projected to occur for a given

composition of the atmosphere if this composition were to remained constant over time and the atmosphere, oceans, and land masses reached thermal equilibrium.) As is discussed in the Effects Report and its review by the SAB, regional variations in temperature, precipitation, and extreme climatic events may be more appropriate measures of climate change impacts, but forecasts of such impacts are at present extremely imprecise.

Alteration of the level of carbon dioxide and other radiatively active gases in the Earth's atmosphere has the potential to change the climate; the scientific information now available does not permit precise prediction of the character and magnitude of the climate changes. Large uncertainties in measures of climate change are likely to persist, even with foreseeable improvements in the General Circulation Models used to investigate the climate consequences of alteration in atmospheric composition. The evaluation of stabilizing options must be done in the face of large uncertainties about the character and magnitude of climate change; these uncertainties add to the difficulty of the evaluation process for stabilizing options but they should not preclude such evaluation from being undertaken. The scientific information now available on the potential for global climate changes suggests that the evaluation of stabilizing options should be vigorously pursued now, rather than delayed while further scientific research attempts to reduce the uncertainties.

The analysis in the Stabilizing Report compares scenarios with continued large increases in emissions of radiatively active gases as the result of worldwide population growth and economic development during the coming century with scenarios in which stabilizing policies reduce or reverse these increases in emissions. The comparison is therefore between scenarios with an accelerating increase in atmospheric concentration levels from increasing emissions of radiatively active gases, and scenarios in which the extent of the increase in atmospheric concentration levels is reduced by holding worldwide emissions to approximately the levels occurring at the present time. While the change in atmospheric composition from <u>current emission rates</u> may result in significant alterations in climate, the scenarios involving <u>continued increases in emission rates</u> during the next century could lead to <u>much greater</u> alteration in the radiative balance and in climate.

The proposed policies needed to achieve the objective of stabilizing emission rates at approximately current levels represent perhaps the most ambitious and comprehensive sustained effort to manage human activity that has ever been attempted in peacetime. These proposed policies would involve massive changes in energy, land use, and other economic sectors on a worldwide scale. Policies intended to stabilize atmospheric concentrations of radiatively active gases at lower levels will involve even greater alterations in worldwide human activity.

The United States is in a position to provide leadership in defining and implementing policy options that can contribute to stabilizing global climate. The analysis in the Stabilizing Report indicates that some of the most important aspects of these options can be foreseen now, even though many important uncertainties remain, both in the scientific understanding of the extent and character of global climate change, and in the problems and promise of the policy opportunities. Congress and the American people should consider what actions should be taken now to provide such leadership on this global problem. The Stabilizing Report provides a good point of departure for discussion of the role that the United States should play in achieving the stabilization of global climate. However, the report is lacking in analyses of economic and social costs or tradeoffs associated with the policy choices, so that it must be regarded as only an initial step in formulating policy options.

## 2.0 INTRODUCTION

### 2.1 Background

In early 1988, the EPA's Office of Policy, Planning and Evaluation (OPPE) requested that the Science Advisory Board (SAB) establish a review panel to examine the two EPA reports to Congress on global climate change. These are The Potential Effects of Global Climate Change on the United States (Effects Report) and Policy Options for Stabilizing Global Climate (Stabilizing Report). Based on this request, the SAB established the Global Climate Change Subcommittee as an ad hoc subcommittee of its Executive Committee. The first of these EPA reports, the Effects Report, was provided to the Subcommittee in October 1988, with the review meeting held on November 17-18, 1988 in Washington, DC. The

Stabilizing Report was released to the Subcommittee in March 1989, with subsequent public review April 4-5, 1989 in Washington, DC.

## 2.2 Charge to the Subcommittee

The Subcommittee has been tasked with the responsibility to review the two draft EPA reports to Congress and to provide advice to the Agency on the following:

- Assessment of the technical adequacy of the two reports, especially the degree to which they address the environmental and other effects of climate change.

- Identification of areas of uncertainty in the reports, and the degree to which this uncertainty may affect the recommendations.

- Consistency of the recommendations with the findings contained in the reports. Specifically (for the Stabilizing Report), are policy options identified that, if implemented, would stabilize current levels of atmospheric greenhouse gas concentrations.

- Other related issues that the Subcommittee believes should be addressed.

## 2.3 Review Process and Format of this Report

The Subcommittee's task was to review the draft Stabilizing Report and to provide advice to EPA on means to improve it, not to provide ongoing oversight of the document as it may evolve from the point of the review. At the April 4-5, 1989 meeting, the Agency staff were provided with detailed comments on each chapter of the report. Following the meeting, they were provided with detailed written comments and a transcript of the meeting.

This report contains information compiled from the meeting transcript and from written comments submitted by each Subcommittee member. Editorial items are generally omitted since they have already been provided to EPA. The Subcommittee's primary goal is to summarize the main points of our advice to EPA, not to reiterate all the advice given to EPA at the public meeting and in our written comments.

This report contains eight major divisions: an Executive Summary (1.0) which highlights the major issues we wish to emphasize; an Introduction (2.0) which provides a discussion of the background and purpose of this review; an Overview (3.0) which presents a broad discussion of the conclusions of the Subcommittee; and four sections which review individual chapters or groups of chapters of the Stabilizing Report. The first of these sections (4.0) contains our review of the Executive Summary; the second section (5.0) contains our review of Chapters I through IV; the third section (6.0) contains our review of Chapter VII; the fourth section (7.0) contains our review of Chapters V, VI, VIII, and IX; and the final section (8.0) contains our summary with respect to the charge of the Subcommittee.

## 3.0 STRENGTHS AND WEAKNESSES OF THE STABILIZING REPORT

The Stabilizing Report in its current draft form has many strengths and some significant deficiencies in need of remedy. These are summarized below.

### 3.1 Strengths and Significant Findings

The report is written in a style that is technically sound yet readily comprehensible for most readers. The first four chapters provide a good overview of scientific knowledge regarding the build-up of radiatively active gases in the atmosphere and the potential for climate alteration on a regional and global scale. Chapter VII provides a lengthy compendium of technical options for reducing emissions of these gases. While the specific characteristics of these options are subject to debate, the chapter provides an excellent introduction for readers unfamiliar with these options. Extensive critical review of the specific options by both proponents and skeptics will improve the basis for evaluation of the options. In our judgment, EPA is to be commended for the extent to which they have organized this material to facilitate such critical examination. However, Chapter VII primarily serves as background concerning technology. The material in the chapter is not directly used in the scenarios.

The analysis presented in chapters V and VI forms the core of the report. EPA has done a good job of formulating the analysis in terms of a small number of future scenarios, which are not

claimed to be accurate predictions, but rather consistent cases describing future changes in population and economic development. A slowly changing world (SCW) and a rapidly changing world (RCW) are examined with and without a set of stabilizing options or policy. Each of the four resulting scenarios are evaluated using a set of modules for energy, industry, agriculture, and land use/natural sources to project emissions over time. An ocean module and an atmospheric composition/temperature module are used to project how the emissions will translate into potential climate change, using the simplified measures of realized global average warming and equilibrium commitment to global average warming. The logical framework for this analysis is readily comprehensible, and the methodology and major assumptions are clearly stated. The sensitivity analysis of Chapter VI provides important insights regarding the extent to which the results depend on specific models and assumptions.

The analysis results indicate that the single most important determinant of emissions is the level of energy demand and the combination of sources used to supply that energy. Carbon dioxide accounts for more than 65% of increased commitments to global warming in all the scenarios (Figure 5-20, p. V-80), and energy dominates deforestation in the magnitude of $CO_2$ emissions. In the two non-policy scenarios the use of coal as a source of primary energy expands greatly, partially as the result of extensive development of coal-based synthetic fuels; in the two stabilizing policy scenarios world coal use expands very little, and other energy sources meet the increased energy demands projected for the next century (Figure 5-9, p. V-40). Population (Figure 5-3, p. V-19) and economic development are important determinants of the end-use fuel demand (Figure 5-6, p. V-34), and in all scenarios the regional allocation of $CO_2$ emissions shows a rapid increase in the share attributed to developing countries. The degree of participation by developing countries in stabilizing policies is one of the most important factors in determining the extent of global climate change by the year 2100 (p. VI-3). Technologies and capital from the United States and other OECD countries could enhance the ability of the developing nations to reduce emissions. Efforts to develop technologies that are more efficient and that produce energy from sources other than fossil fuel will be critical to achieving emissions reductions from nations throughout the world (p. 88). Sensitivity analysis (Figure 5-21, p. V-83; Table 6-1, p. VI-7) indicates that reduction in many sources and cooperation by

many countries will be needed to have a major impact in reducing emissions (Finding III, p. 87). Sensitivity analysis further indicates that the results of the analysis are less sensitive to some of the many assumptions used in the ocean $CO_2$ module and the atmospheric composition/temperature module (Table 6-1, p. VI-7). However, the timing and the magnitude of temperature change depend directly on the assumed temperature sensitivity to doubled $CO_2$ and the rate of heat uptake by oceans. The analytical results depend on the models and data used, and these data and models clearly warrant further investigation.

### 3.2 Weaknesses

The Stabilizing Report should begin with a discussion of the analytical approaches and the choice of stabilizing options to be examined. An Executive Summary of 91 pages is too long to hold the interest of many readers, and we recommend a shortened version emphasizing the analysis of stabilizing options rather than the science issues discussed in Chapters I-IV. Detailed documentation of the data base, the analytical modules used in Chapters V and VI, and analytical results (e.g., energy prices) is urgently needed. The Subcommittee understands that EPA is producing such documentation. The flow of the policy chapters (V, VI, VIII, and IX) is broken by the lengthy discussion of technical options in Chapter VII; this chapter might be moved up to follow Chapter IV or made an appendix. A concluding chapter summarizing the evidence in support of the findings (pages 83-91 of the Executive Summary) would be a useful addition to the Report.

A major weakness of the draft report lies in Chapters VIII and IX. These chapters focus rather narrowly on near-term options to reduce energy demand, with relatively minimal discussions of R&D and opportunities for United States leadership through international cooperation. The Subcommittee believes that these chapters should be expanded to include more detailed discussion of opportunities for development, technology transfer, and commercialization of technologies to enhance energy efficiency and replace dependence on fossil fuels, especially in developing countries. These chapters should be more closely integrated with Chapters V and VI. They should give the reader a sense of priorities, not just a list of possibilities, and they should indicate further steps needed for more detailed analysis of both domestic and international options.

A second major weakness in the report is that it provides little information on the costs or possible trade-offs involved in choosing between and implementing various stabilizing options. The discussion of Chapter VII and the analysis of Chapters V and VI indicates that the stabilizing policies will have substantial impacts on energy prices, land use, agriculture, and industrial development. A summary of costs would be an extremely useful addition to this draft report and the appropriate focus of a major effort in further EPA study of stabilizing options.

### 3.3 The Need for Further Planning and Analysis

The Stabilizing Report is an appropriate response from EPA to the request made of it by Congress. The analysis and findings may disappoint those who had hoped that stabilizing the atmosphere to avoid climate change could be accomplished with modest efforts by the US in cooperation with other industrialized nations. The findings indicate that stabilizing the atmosphere may be possible only in the next century, at concentration levels of radiatively active gases that may alter climate in significant ways, and then only as the result of a great effort by many nations involving high levels of innovation . It seems clear that investigation on the effects of global climate change, stabilizing options, and research planning relating to both effects and technological innovation should be undertaken in a coordinated fashion, and that the United States Government should commit significant resources to such integrated planning as a follow-on effort to the two Reports to Congress prepared by EPA.

Concern over the prospect of global climate change is now widespread in the United States and in many other nations, and numerous international study efforts are being launched. The two EPA Reports to Congress should make important contributions; they represent perhaps the most extensive investigations on effects and stabilizing options yet undertaken by any nation or international group. But the level of analysis and investigation that they represent is regarded as an initial effort. The insights from these reports should be used to guide much more extensive investigations on global climate change effects in the United States and in other countries, on stabilizing policies that can be implemented with existing technologies, and on the potential for research and development to develop new technologies for further reductions in emissions at affordable costs.

What level of climate stabilization is needed, and what level can the nations of the world afford, consistent with their aspirations for economic and social development? Both the process of selecting policies and the process of implementing policies will be difficult; selection and implementation decisions will evolve over decades based on the actions of many nations. The United States has the technical and analytical skills and resources to play a leading role in investigating the threat posed by global climate change and in developing options for responding to this threat. United States leadership in scientific research, planning, and technological innovation can provide a basis for better decision making by the United States and by many other nations. The SAB Global Climate Subcommittee commends both EPA and its Congressional sponsors for the progress achieved so far in the two reports to Congress. We urge that expanded planning and analysis efforts on global climate change be vigorously pursued by the Federal Government both directly and through participation in international studies.

## 4.0 COMMENTS ON THE EXECUTIVE SUMMARY

At 91 pages, the draft Executive Summary is not a summary but a short report, and it is sufficiently long and complex to deter many readers. The findings at the end of this section should be placed at the beginning. This "summary of the summary" especially should be carefully reexamined to assure that it reflects the most important conclusions from the report and that its tone is appropriate. Specific examples of wording problems, inappropriate tone, and poorly supported conclusions were discussed by Subcommittee members at the meeting April 4-5.

The Executive Summary should include a more explicit discussion of why EPA chose to focus on options that stabilize emission rates rather than the much more stringent options needed to stabilize atmospheric concentrations. The basis for the numbers in Table 1 as model-based estimates should be made evident, and the implications for the feasibility of stabilization at various levels need exposition.

The Executive Summary might focus more on the methods and conclusions regarding stabilizing options and less on the scientific knowledge of how radiatively active gases affect climate. The latter material has been the subject of many other

studies, and the first four chapters provide a good review for the unfamiliar reader. The sensitivity analysis (Table 6, its footnotes, and associated text) seems overly lengthy for the Executive Summary. The implication of the sensitivity analysis is that uncertainty in the level of future coal use has a large impact on projected climate change. The projected extent of climate change as represented by equilibrium warming commitment is less sensitive to many of the modeling assumptions for ocean $CO_2$ and heat uptake, atmospheric chemistry, and feedbacks. These important results could be presented more clearly and with less detail.

## 5.0 COMMENTS ON CHAPTERS I THROUGH IV

### 5.1 General Comments

Overall, these four chapters do a good job of assembling and describing a broad range of relevant scientific information dealing with current knowledge of nature's response to increasing levels of greenhouse gases. The inclusion of all major gases in a common framework is a significant and important extension of previous work. In the text, both the status and uncertainty of the science are well described. However, many of the cautions and caveats are lost in the statements of Findings and Conclusions that accompany each chapter. The Subcommittee had a number of editorial comments concerning slight inconsistencies of information from place to place, and dealing with clarity of presentation, but basically we felt that the science was well described. We find the liberal use of graphs and figures add to the clarity of presentation. However, the captions for many of the figures could be enhanced to provide better explanations of what the figure illustrate. In some cases it may be appropriate to box the figure with more lengthy explanatory text. This approach would be particularly useful for figures drawn from the Chapter I through IV material that appear in the Executive Summary.

The Subcommittee had two substantive concerns about the description of the science. First, the principal methodology relies on model output that focuses exclusively on global temperature change as a surrogate for climate change. While the report acknowledges that temperature change per se is not the sole measure of impact, nor arguably the most meaningful, this point needs to be amplified considerably. Second, while the report properly focuses on scenarios through 2100, it would be useful and

important to include a discussion of what is known concerning longer range climate change. In fact, we held a useful discussion of this topic during our review meeting. Policy discussion should recognize the potential that buildup of greenhouse gases may have very long-term consequences for climate, because the residence times for greenhouse gases in the atmosphere are long.

The report discusses a methodology based on simplified, integrated models to generate scenarios of climate change through the year 2100. These models incorporate not only nature's response but also the social and economic activities driving future emissions of greenhouse gases. Principal input to the models is the specification of scenarios, including assumptions and judgments about population growth, economic growth, and demand for and availability of various technologies for energy supply. Principal output from the models is the variation of globally averaged temperature with time, which is taken as a surrogate for climate change. Change is driven by emission of greenhouse gases from future human activities that are derived from a series of economic models (described in later chapters). The accumulation and interaction of atmospheric greenhouse gases serve as input to the models of physical climate change. To describe the physics and chemistry, the report implements a simplified model of atmospheric chemistry, a parameterized representation of radiative forcing from greenhouse gases, and a one-dimensional transient model of temperature change that accounts for the flow of heat (and $CO_2$) between the atmosphere and oceans.

At this time the use of linked, simplified models is probably the best available methodology to examine scenarios of climate change that support analysis of policy options. These are not the full-fledged models of atmospheric chemistry or oceanic and atmospheric circulation most often cited as giving forecasts of future climate impacts. Simplified models like these have been used often in the past to assess the basic picture of climate change with time in a manner that captures many important features of far more complex models. While complex models include substantially more detail and resolution in their description of atmospheric chemistry, radiative transfer, and climate, their use for integrative analysis is prohibitively costly and cumbersome, especially if large numbers of sensitivity cases are to be investigated. Yet simple models are deceptive in results and their

validity; a comparison with more sophisticated and detailed models is warranted for calibration.

This report for the first time puts a complete set of models together in a unified package that integrates treatment of all the major trace gases responsible for greenhouse forcing. The report builds from previous efforts, utilizing sensible approaches and best available results from more complex models. The report also does an excellent job of describing major areas of uncertainty, and in showing the dependence of results on uncertainty in the science that can be captured in their modeling framework.

The report recognizes that temperature change alone is not the sole measure of impacts from climate change, but this point should be amplified extensively. Far more than global average temperature, changes in sea level, the hydrological cycle, and climate variability (e.g., the frequency of drought or intense storms) are the more relevant variables to assess impacts in particular regions. However, these variables are far more uncertain in model predictions. Assessment of policy options to respond to potential effects on agriculture, ecosystems, or human impacts require far more information than is available from global temperature change alone. Also, impacts will be differently distributed across the globe at locations and times that are difficult to predict. The Subcommittee is concerned that by placing so much emphasis on global temperature, the non-expert reader might be led to questionable conclusions about the effectiveness of policies. For example, one might conclude that reducing the temperature increase by half could reduce impacts by half, and that would be a naive and misleading conclusion.

We found the choice of four scenarios to be useful and illuminating. However, the narrative description of results, the lack of certain analyses, and the lack of a base case make it difficult to unravel sensitivities that allow one to understand the meaning of the results. For instance, there is limited analysis of the range over which policies might be varied, the impediments to implementation, or the possible trade-off between various approaches. Also it appears that even the assumptions in the non-policy scenarios already may include overly optimistic projections concerning the pace of implementation of efficiency steps in end-use applications of energy, and concerning the availability of alternate (non-fossil fuel) sources of energy. The

net effect may well be to underestimate the magnitude of societal response that might be required to limit future climate change.

## 5.2 Comments on Chapter I

This chapter does a good job of summarizing the genesis and goals of this study. The Subcommittee notes that the report does not actually respond to the Congressional charge to examine policies that stabilize levels of greenhouse gases at current concentrations in the atmosphere, and this should be acknowledged more clearly in the introduction. It might well be stated that the goal may be presumptuous, since we do not completely understand Nature's cycles well enough to know if humans can indeed control the atmospheric composition. Also, water vapor, the dominant greenhouse gas, is not directly controlled by human activities. However, current knowledge allows us to make some estimate of the magnitude of emission control, and time, for atmospheric composition to equilibrate. Admittedly the long-term estimates involve large uncertainly that must be described. It may well be true that to accomplish this objective is not possible without unacceptable and unworkable international actions and sacrifices. Nevertheless, working backward from that goal would provide an important bound on what policy changes would accomplish.

While reasonably complete in the review of prior studies, the Introduction should acknowledge the proceedings of the Villach Workshop, "Developing policies for responding to climate change". Also, the report does not cite or describe proposals produced in the Canadian Climate Conference, the Hamburg Conference, or indeed in several recent Bills submitted to Congress, which already make specific calls for target reductions in emissions, and other steps. The Stabilizing Report could contribute to a better understanding of those proposals.

The Introduction should also clarify what the report does not do: provide cost estimates, or analyses of the policy proposals that would allow one to judge the trade-off between one or another, including costs and societal impacts. Nor does the report address the issues associated with implementation of policies in the United States and globally. At the outset it should be acknowledged, in the context of setting policy, that science cannot yet provide meaningful criteria to differentiate among impacts associated with

different rates and magnitudes of climate change. That should be stated as an important goal to aid future policy analyses.

## 5.3 Comments on Chapter II

This is an excellent compilation and summary of the science concerning the data and understanding of the buildup of the most important greenhouse gases. Our comments concerning this chapter were mostly editorial concerning details of presentation and consistency of description.

We recommend that the discussion of sources and sinks should acknowledge the lack of quantitative understanding of the current buildup of carbon dioxide in the atmosphere. There is an imbalance between known sources and sinks that might be masking a large unknown sink for $CO_2$. That is to say: compared with emission rates, the buildup of atmospheric $CO_2$ is smaller than we can readily explain. This topic is discussed in later chapters, but should be brought out here as a major scientific uncertainty in the greenhouse issue. When processes that control atmospheric $CO_2$ are not clearly understood, it is difficult to predict the effectiveness of policies to limit $CO_2$ emissions. It is possible in the future that analyses of changing isotopic ratios in atmospheric $CO_2$ may distinguish between competing sources of carbon: anthropogenic additions from older fossil fuel carbon versus changes in younger sources associated with the biosphere.

This chapter suggests that natural sources and sinks remain in balance, implying that anthropogenic emissions account for the entire buildup of $CO_2$, but that is an assumption, not a statement of certain scientific knowledge. Moreover, climate change might induce changes in the natural cycles that would lead to further imbalance, increasing or decreasing future rates of buildup.

## 5.4 Comments on Chapter III

Chapter III addresses the data and model results for the analysis of climate change. This is a crucial section, since it describes the extent to which we can accurately predict climate change, given changes in atmospheric composition, with our present capabilities, and it enumerates the many difficulties that must be overcome in order for our predictive capabilities to improve. The chapter includes a discussion of the older paleoclimate data, as

well as attempts to reconstruct the relatively recent past from archived measurements. Basic scientific understanding and most aspects of uncertainty are discussed well within the bulk of the chapter. However, the summary statements in the findings and conclusions do not reflect fully the state of uncertainty.

Perhaps the most important information in this context is the record of historical temperature change, which is reasonably described in the text. While the text states that the gradual warming seen over the past century is not inconsistent with the increase in greenhouse gases over the period, it properly calls attention to the cooling trend for the United States in the data between 1940-1975 as evidence that other factors must be operating. Some effort has been made to attempt to sort out effects of known or assumed influences on climate variation, for instance work by Hansen and by Gilliland in the early 1980's. However, their studies served to indicate how difficult it would be to remove these effects with certainty. The findings in the summary statements (perhaps incorrectly) portray the record of warming over the past 100 years as qualitatively consistent with expectations from greenhouse models. Mention should be made of published analyses, most recently by Ramanathan, that another decade or two of observation will be required to confirm models, if warming occurs as the models now predict. As yet, it is premature to argue that increases in greenhouse gases explain the record of temperature change, considering the extent of natural variability.

While there are many speculative proposals concerning feedback processes that could amplify or reduce future climate change, the chapter focuses its remarks on mechanisms that could amplify greenhouse warming, while ignoring those that might reduce warming. For example, the findings and text describe possible bio-geochemical feedbacks that might enhance emission of greenhouse gases, while ignoring the possibility that higher levels of atmospheric $CO_2$ might stimulate biospheric growth rates, thus reducing the future buildup of $CO_2$ in the atmosphere. Similarly, the chapter does not describe the work by Somerville on possible changes in the microphysical properties of clouds, which would enhance reflection of sunlight and reduce future warming. Finally, it is somewhat misleading to refer to several feedback processes as having been ignored in past scientific studies; a more accurate characterization would be that many processes have been suggested that may influence climate feedback, but they are still too little

understood to be incorporated quantitatively into models. In this regard it is not yet possible to distinguish whether physical or biogeochemical mechanisms will be most important in determining ultimate effects, as current scientific understanding is not yet that precise.

The discussion of realized versus equilibrium temperature change is important and relevant. However, an additional point should be made clearly: it will be very difficult to establish ultimate equilibrium climate sensitivity from direct observation. Models to date, and for the foreseeable future, are likely to remain sufficiently uncertain that they will need to be calibrated against observational data. However, measurement can only assess realized temperature change. In the models, a variety of values for sensitivity (equilibrium temperature change), in combination with an ocean model producing the appropriate delay, can result in identical amounts of realized warming at a particular date. This means it will be quite difficult to establish ultimate climate impacts from given levels of atmospheric greenhouses gases.

## 5.5 Comments on Chapter IV

This chapter summarizes a great deal of information concerning anthropogenic emission rates of greenhouse gases. We suggest that emissions should be characterized as contributing to greenhouse radiative forcing, rather than contributing to warming. The relation of the concentrations of radiative active gases to warming is complex and, as yet, poorly understood. The use of global average warming as predicted with a simplified model is an appropriate indicator, or summary measure, for this initial effort at investigating stabilizing options. It should be clearly explained that we have relatively poor ability to predict global average warming, and that more complex characterizations of climate change will be needed to assess the seriousness of the potential impacts.

## 6.0 COMMENTS ON CHAPTER VII

There was some discussion concerning whether or not this large chapter should be left in the middle of the draft Stabilizing Report or moved to the back as an appendix. Some members of the

Subcommittee felt that it created too much separation between the related issues in the chapters on either side, while others suggested that this chapter was too important to be relegated to an appendix. The chapter is well written and provides much useful information. Nevertheless, we noted unevenness in both the levels of detail and documentation.

Our major comments in the Energy Services Section concern fuel economy and the way the chapter relates to the scenarios analysis. We are concerned about the levels of automotive fuel economy assumed in the analysis. For the year 2000, fifty mpg may be an overestimate of what can be achieved for new cars without affecting comfort or lifestyle , although it is certainly achievable on a small scale or demonstration basis. A more reasonable figure for what could be achieved with a large implementation program might be 40 mpg. (However by 2025 or later, automotive fuel economy could be 50 mpg or even higher.) In addition, the report should mention the difference between nominal and real fuel economy. This difference for new cars is at least as important as degradation in fuel economy over the life of an automobile.

The Subcommittee questioned how information presented in this chapter was incorporated into the scenario analysis. The chapter presents information on many different technologies, especially non-fossil fuel energy technologies such as solar, biomass, nuclear, and technologies for improving the efficiency with which energy materials are transported, converted from one form to another, and applied to meet end-use needs. For many of these technologies, the potential impediments to more extensive use merit further discussion. For example, the safety issue, the waste disposal issue, and the risks of diversion of nuclear fuel materials to weapons or terrorism are widely regarded as posing formidable problems for extensive worldwide use of nuclear power. Similarly, water and land availability and soil conditions may limit the extent that biomass technologies can be used in some areas of the world.

There should be more information presented in Chapter VII on the basis for the choice of energy efficiencies and other parameters used in the analysis of Chapter V. Such discussion is important for the sensitivity cases, as well as the four main scenarios. The reader should have an appreciation for why these cases are sensible choices for investigation, given the summary

provided in Chapter VII on the potentials and problems for the various technologies.

Further discussion is also needed on other topics in the section on energy supply. Examples include: natural gas reserves in other parts of the world such as in the Soviet Union; production of liquid fuels such as ethanol and methanol, and electric power generation from biomass; and assessment of plausible implementation scenarios for the wide range of emerging solar technologies.

In the Forestry Section, also, there is insufficient attention given to the impediments to implementing the policy alternatives discussed, especially at the international level. In particular, cultural, economic, social, and other factors make it difficult merely to plant trees on a massive scale in many countries. What is needed is an agroforestry-societal system that seeks not just to maximize carbon dioxide alleviation, but more importantly, seeks to establish economically robust and long-standing practices that can replace slash and burn agriculture with forestry, that can identify polycultures consisting of various trees that would be of direct economic benefit to the local populace and therefore would stand a chance of being accepted by them, rather than trying to introduce economically risky monocultures of trees whose only purpose is to sequester carbon.

Similar comments apply to the Agriculture Section. Specifically, there is insufficient discussion of potential feedbacks (e.g., how climate change might change rates of methanogenesis); how issues of scale of implementation are important; and what are the impediments to implementing changes in farming practices. This section also needs more discussion of limitations in the data base; for instance, very little is known about methane production in rice paddies in actual practice in Asia, yet that is likely a dominant agricultural source of methane.

## 7.0 COMMENTS ON CHAPTERS V, VI, VIII, IX

Given the great breadth and complexity of the material covered in these four chapters, it would be useful to add a short chapter at the end of the report to summarize the important insights from

the examination of stabilizing options to support the findings stated in the Executive Summary.

The modeling system for scenario evaluation that is described in Chapter V represents a commendable innovation in its comprehensiveness and its balance of appropriate level of detail. The major weakness is the lack of detailed documentation for the set of analysis modules, the extensive data base required, and the details of the results for the scenarios examined.

The energy modeling in particular appears to be a major step forward in marrying top-down and bottom-up approaches. The approach permits a projection of energy end-use demands by region based on population and economic development assumptions, and then a calculation of how alternative energy supplies would be allocated to meet these demands. The top-down aspects involve substantial aggregation within regions, among fuel forms, and among technologies. The choice of demand levels, income elasticities, price elasticities, resource supplies, and technology costs will have a major influence on the resulting projections of energy use and emissions. These choices can be a subject for considerable debate among energy experts, and the diversity of opinion expressed by members of the Subcommittee is a microcosm for what can be expected from the larger community.

In future exercises of this type, it is desirable to expand the most important aspects of the model (use of coal versus substitutes including conservation) and examine factors determining technology choice rather than aggregate elasticities. The advantage of the existing system is that it provides a systematic and comprehensive accounting of energy supply and demand as these evolve over time, by region, and under different assumptions for policy. It therefore facilitates careful examination of how conclusions regarding the impact of policies in reducing emissions depend on specific model assumptions and data. Such examination should lead to important insights regarding stabilizing options relating to energy use. The analysis presented in the EPA Report is appropriately viewed as a good beginning in this process. To progress further, analysts outside of EPA will need access to detailed technical documentation of the modules, the data bases, the scenario results (energy quantities and prices over time), and perhaps the computer codes used in EPA's analysis.

A major theme needing increased emphasis in these four chapters is the importance of energy R&D, particularly on technologies that reduce the level of coal use. For many countries, coal will be the most accessible and least costly alternative for energy in the 21st century. Its use, however, results in even higher $CO_2$ emissions than from natural gas or petroleum, which have been the most important energy sources for the 20th century. A mix of technologies to avoid expanded coal use is a critical component of policy for stabilizing emissions. These technologies include alternative means for electric power generation such as solar photovoltaics and nuclear power, higher efficiencies and conservation initiatives, and use of biomass fuels. Commercialization of these technologies in both industrialized and developing countries will involve substantial effort, for there are many formidable problems to be overcome. Among these are the acceptability of expanded use of nuclear power, the land use and water availability problems associated with biomass, and the increased costs of alternatives compared to the use of coal for power generation and synthetic fuels. Another area deserving careful investigation is the development of less energy-intensive methods for basic materials processing such as steel, cement, glass, and fertilizers.

The analysis of Chapter V and VI indicates the need for careful reassessment of energy R&D with respect to minimizing emissions of carbon dioxide and other radiatively important gases. The Subcommittee believes that exploration of opportunities for energy technology development and commercialization is an important topic for this report and for future studies on stabilization. An important aspect to be addressed is how the energy needs of developing countries will be met. The successful commercialization of the technologies needed to reduce emissions will require capital and technical knowledge that are readily available in the United States and other industrialized countries but scarce in developing countries. Successful commercialization will also require that the technologies fit with culture, institutions, and infrastructure needs of these countries. The report should devote more discussion to these issues, and examples of innovation in energy policy in the United States and in other countries would be useful for illustration. A number of such examples were discussed at the Subcommittee meeting April 4-5, 1989. A policy option that deserves further investigation is establishment of technology transfer centers in Third World countries. These centers would

provide technical assistance to encourage adoption of energy-efficient and renewable energy technologies.

While in general Chapters V and VI are carefully written, in some places the tone needs to be more dispassionate and scientific. The discussion should not give the appearance of advocacy of policy alternatives, but rather describe the alternatives, their potential to reduce emissions, and the potential impediments to their implementation, without including value judgments on the desirability of the alternatives.

The sensitivity analysis is useful, as it can provide important insights into the robustness of the conclusions drawn from the analysis of the scenarios. The choice of the sensitivity cases, their presentation in tables and figures, and the accompanying text should be revised to highlight the major findings and insights rather than a presentation of a large number of detailed results. It may be appropriate to replace the material in the draft report with a less detailed version and place in an Appendix a comprehensive annotated set of sensitivity case results.

A graphical presentation on the response of the four alternative ocean/atmosphere interaction models to increased $CO_2$ was given to the Subcommittee at its meeting on April 5. This material will be a useful addition to the report. Some attention to the evaluation of scenarios with and without stabilizing policy in the post-2100 period would also be a useful addition to the report. One issue of concern is the potential for additional sea level rise in the post-2100 period from the melting of glacial ice.

Chapters VIII and IX need extensive revision. These chapters were intended as an overview of a range of policy options, but their focus is too limited to near-term alternatives for reducing energy use. These chapters do not build on the modeling results of chapters V and VI, but rather reflect the judgment of energy experts at EPA workshops. The Subcommittee believes that far more attention should be given in the report to energy R&D and commercialization options and to examination of means to facilitate emissions reduction in developing countries that are consistent with the aspirations of these countries for energy development and economic growth.

The discussion of policy initiatives for near-term reduction in energy use has useful aspects but also some limitations. The discussion is a compendium of ideas, with relatively little rationale for selection of options or setting priorities among the options. Members of the Subcommittee questioned whether the material presented had the appropriate level of detail and balance. For example, the increased number of light trucks in the United States vehicle fleet has significant implications for fuel economy that should be discussed. More emphasis might be placed on "gas guzzler" and fuel tax initiatives, as opposed to the extensive consideration given to regulation through fuel economy standards. More discussion is needed on the experience in the United States and European countries with policy initiatives, particularly problems to be overcome.

The policy options for stabilization are not limited to those that can be implemented in the next decade. Some of the most important actions that the United States might undertake involve the development of new technologies, institutions, and incentives that will permit large reductions in emissions in the 21st century. Decisions to deploy these technologies, alter institutions, or create new incentives are not necessary now. These decisions can be made at a later time, when scientific research should give a clearer picture of the consequences of global climate change, and research on these longer-term policy initiatives should give additional information on their problems and promise. However, to support decisions in the early 21st century on stabilization, such investigations need to be pursued vigorously during the remainder of this century.

## 8.0 SUMMARY WITH RESPECT TO THE SUBCOMMITTEE'S CHARGE

In general, the technical adequacy of the draft Stabilizing Report is good; the report will be extremely useful as a compendium of information relevant to the assessment of stabilizing options, and the basic analysis framework is appropriate. The main technical deficiencies are the lack of documentation of the Chapter V analysis models and detailed results; the omissions in Chapters VIII and IX, especially on R&D, technology transfer, and commercialization; and the lack of cost information on the technologies and stabilizing options.

The draft Stabilizing Report does a reasonable job of presenting uncertainties, especially on the scientific issues in Chapters I through IV. It could do more in discussing uncertainties in the extent to which new and emerging technologies can contribute to reducing emission rates of the radiative active gases.

The draft Stabilizing Report presents findings and conclusions, rather than recommendations; in most cases, these findings and conclusions are supported by the material assembled in the text. The Report does not address stabilizing atmospheric concentrations of greenhouse gases at levels near the present composition of the atmosphere: the authors judged this to be an infeasible goal, and the Subcommittee agrees with this judgment. The problem of stabilizing emission rates of these greenhouse gases and limiting the extent of potential climate change in the next century appears to be formidably difficult; the problem of stabilizing atmospheric concentrations will be far more difficult.

The Subcommittee believes that assessment of the potential effects of global climate change, evaluation of stabilizing options, and research on climate change, on effects, on technologies that may reduce emission rates, and on the institutional and implementation issues in deploying these technologies should all be pursued immediately and vigorously as part of a coordinated program, within EPA, within the federal government, and through international organizations. The global climate change work accomplished by EPA that the Science Advisory Board has reviewed should be a useful initial step toward this program of coordinated planning and research.