

Originally Processed With FOIA(s):  
2005-0336-F

FOIA Number:  
2005-0336-F

# FOIA MARKER

**This is not a textual record. This is used as an  
administrative marker by the George Bush Presidential  
Library Staff.**

---

**Record Group/Collection:** George H.W. Bush Presidential Records  
**Collection/Office of Origin:** Science and Technology Policy, Office of (OSTP)  
**Series:** Bromley, D. Allan, Files  
**Subseries:** Global Climate Change Files

---

**OA/ID Number:** 62048  
**Folder ID Number:** 62048-004

---

**Folder Title:**  
Environment: General [5 of 6] [1991]

---

**Stack:**

**Row:**

**Section:**

**Shelf:**

**Position:**

**0**

**0**

**0**

**0**

---

logged

"CORRESPONDENCE TRACKING"

TYPE: ACTION DOCUMENT NUMBER: 9120470

\*\*\*\*\*

FROM: HABICHT, F. HENRY

TO: DR. BROMLEY

Sara

DATE OF  
CORRESPONDENCE: 02/14/91

SUBJECT: U.S. - E.C. JOINT CONSULTATIVE GROUP ON SCIENCE AND  
TECHNOLOGY.

\*\*\*\*\*

ASSIGNED TO: Thomas Ratchford SB

ACTION REQUIRED: AS NECESSARY

\*\*\*\*\*  
SENDER'S DUE DATE: OSTP DUE DATE:

DATE COMPLETED: 3/12/91

\*\*\*\*\*

COPIES TO: D. Allan Bromley  
Nancy Maynard  
Maryanne Bach

\*\*\*\*\*

WHITE HOUSE TRACKING #: CONTACT PERSON:

REMARKS: Please clear from tracking. No response necessary.

DATE RECEIVED: 02/20/91

FILE: ENVIRONMENT\* International





UNITED STATES ENVIRONMENTAL PROTECTION AGENCY  
WASHINGTON, D.C. 20460

7120470

FEB 14 1991

91 FEB 20 P2:57

OFFICE OF THE  
DIRECTOR

OFFICE OF  
THE ADMINISTRATOR

Dr. Allan Bromley  
Assistant to the President  
Office of Science and Technology Policy  
The White House  
Washington, D.C. 20500

Dear Allan:

Many thanks for your letter of January 22, 1991 inviting me to represent E.P.A. at the first meeting of the newly-established U.S.-E.C. Joint Consultative Group on Science and Technology. I would be pleased to represent E.P.A. and look forward to the discussions with great interest.

Since I may have to be absent during part of the meeting, I designate Erich W. Bretthauer, Assistant Administrator for Research and Development, as my alternate.

In addition, I would like the following individuals to attend as observers:

Alan Hecht, Deputy Assistant Administrator, OIA  
Carl Mazza, Senior Science Advisor, OAR  
Carl Gerber, Senior Science Advisor, ORD

Thank you again for including EPA as a member of the U.S. delegation to this important meeting.

*Let me know  
anything else we can  
do in the preparation or  
follow up. - Warm regards,*

Sincerely,

F. Henry Habicht II  
Deputy Administrator

cc: Erich Bretthauer  
Alan Hecht  
Carl Mazza  
Carl Gerber



"CORRESPONDENCE TRACKING"

TYPE: INFORMATION

DOCUMENT NUMBER: 9120367

\*\*\*\*\*

FROM: COADY, E. PATRICK (THE WORLD BANK)

TO: DR. BROMLEY

DATE OF  
CORRESPONDENCE: 02/06/91

SUBJECT: GLOBAL ENVIRONMENTAL FUND: SCIENTIFIC PANEL

\*\*\*\*\*

ASSIGNED TO:

*2000 R. Cunniff*  
*DRB*  
*2-12*

ACTION REQUIRED:

\*\*\*\*\*

SENDER'S DUE DATE:

OSTP DUE DATE:

DATE COMPLETED:

-----

\*\*\*\*\*

COPIES TO: Nancy Maynard  
D. Allan Bromley

\*\*\*\*\*

WHITE HOUSE TRACKING #:

CONTACT PERSON:

REMARKS:

*No response req'd.*  
*WSB 2/15/91*

DATE RECEIVED: 02/11/91

FILE: ENVIRONMENT



"CORRESPONDENCE TRACKING"

TYPE: INFORMATION

DOCUMENT NUMBER: 9120367

\*\*\*\*\*

FROM: COADY, E. PATRICK (THE WORLD BANK)

TO: DR. BROMLEY

DATE OF  
CORRESPONDENCE: 02/06/91

SUBJECT: GLOBAL ENVIRONMENTAL FUND: SCIENTIFIC PANEL

\*\*\*\*\*

ASSIGNED TO:

ACTION REQUIRED:

\*\*\*\*\*

SENDER'S DUE DATE:

OSTP DUE DATE:

DATE COMPLETED:

-----

\*\*\*\*\*

COPIES TO: Nancy Maynard  
D. Allan Bromley

\*\*\*\*\*

WHITE HOUSE TRACKING #:

CONTACT PERSON:

REMARKS:

DATE RECEIVED: 02/11/91

FILE: ENVIRONMENT

9/20367

The World Bank

Washington, D.C. 20433  
U.S.A.

RECEIVED

91 FEB 11 P4:35

DATE: February 6, 1991

TO: Distribution *egc*

FROM: E. Patrick Coady, U.S. Executive Director *OFFICE OF THE DIRECTOR*

SUBJECT: Global Environmental Fund; Scientific Panel

A brief telephone conversation with Dr. Tolba (UNEP), on February 5, revealed the following information about the status of the GEF's Scientific and Technical Advisory Panel.

A letter addressed to 50 governments requesting the submission of candidates was delivered to our UNEP representative in Nairobi, Chris Ashley. From this solicitation, UNEP expects to receive about 150 names, from which 40 will be selected. The names of the 40 will be circulated to the governments. The 10 Panel members will be selected from those 40 names and the remaining 30 will become a roster for selection to serve as individual project advisers. The 10 Panel members selected will be drawn from each specialty, probably 2, and each region.

There will be a developed country Chairman (Stewart of USA) and a developing country Vice Chairman.

My sense is that Tolba has his own short list.

Distribution:

Assistant Secretary E.U. Curtis Bohlen, Department of State  
Assistant Administrator Richard Bissell, U.S.A.I.D.  
Assistant Administrator Timothy Atkeson, E.P.A.  
Associate Chief George Leonard, Department of Agriculture  
Mr. Doug Buffington, Department of Interior  
Assistant Secretary Thomas Lovejoy, Smithsonian Institution  
Mr. D. Allan Bromley, White House  
Deputy Assistant Secretary George Folsom, Department of Treasury  
Mr. Nelson Coar, Department of Treasury  
Mrs. Anna Quandt, U.S.A.I.D.  
Mr. Jack Boyle; Ms. Molly O'Neal, Department of State



"CORRESPONDENCE TRACKING"

TYPE: ACTION

DOCUMENT NUMBER: 9120282

\*\*\*\*\*

FROM: HERZFELD, CHARLES M.

TO: DR. BROMLEY

DATE OF  
CORRESPONDENCE: 02/01/91

SUBJECT: FORMATION OF A STRATEGIC ENVIRONMENTAL RESEARCH AND  
DEVELOPMENT PROGRAM (SERDP) COUNCIL.

\*\*\*\*\*

ASSIGNED TO: D. Allan Bromley

ACTION REQUIRED: RESPONSE

\*\*\*\*\*  
SENDER'S DUE DATE: OSTP DUE DATE: 02/15/91

DATE COMPLETED: -----

\*\*\*\*\*

COPIES TO: Michelle Van Cleave  
Nancy Maynard

\*\*\*\*\*

WHITE HOUSE TRACKING #: CONTACT PERSON: DR. JOSEPH V. OSTERMA

REMARKS:

DATE RECEIVED: 02/06/91

FILE: ENVIRONMENT-SERDP

\* Bromley  
Membership -  
SERDP

THE WHITE HOUSE  
WASHINGTON

February 21, 1991

Dear Charles:

I shall be happy to accept membership on your SERDP Scientific Advisory Board and, at some time that is mutually convenient, would look forward to being briefed by Dr. Osterman on the proposed activities of that board.

With all best wishes,

Sincerely yours,



D. Allan Bromley  
Assistant to the President  
for  
Science and Technology

Dr. Charles M. Herzfeld  
Director of Defense Research and Engineering  
Room 3E1014  
Department of Defense  
Washington, D.C. 20301-3010



9120282



## DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

WASHINGTON, DC 20304-3010

91 FEB 6 P2:40

1 FEB 1991

Honorable D. Allan Bromley  
Assistant to the President  
for Science and Technology  
Executive Office of the President  
Washington, D.C. 20506

OFFICE OF THE  
DIRECTORDear Dr. Bromley: *Allan*

I am writing with regard to the Strategic Environmental Research and Development Program (SERDP). Public Law 101-510, the National Defense Authorization Act for Fiscal Year 1991, directed the Secretary of Defense to initiate this program. The purposes of the program are in part, to address environmental matters of concern to the Department of Defense and the Department of Energy through support for basic and applied research, and development of technologies that can enhance the capabilities of the departments to meet their environmental obligations.

The law calls for formation of a SERDP Council to prescribe policies and procedures to implement the program, and identifies the membership of the Council. In addition, a SERDP Scientific Advisory Board is required, and the law identifies the sources of membership on this Advisory Board. The Science Advisor to the President, or his designee is stipulated by the law as a permanent member of the Advisory Board.

I would welcome your participation on the Advisory Board, but certainly understand the demands on your time if an alternate is more feasible. If you would like more information on the program, I would be pleased to have Dr. Joseph V. Osterman give you a complete briefing. He is my Director of Environmental and Life Sciences, and may be reached in the Pentagon at (703) 697-8714.

Please let me know who will represent your office at your earliest convenience.

Sincerely,

*Charles*  
Charles M. Herzfeld



"Document Control"

TYPE: ACTION DOCUMENT NUMBER: 9120565  
ORIGINATOR: 02 STATUS I DIRECTORATE STATUS C  
\*\*\*\*\*

FROM: STEWART, Dick: U.S. DEPARTMENT OF JUSTICE

TO: DR. BROMLEY

DATE OF  
CORRESPONDENCE: 01/24/91

SUBJECT: REPORT ON THE COMPREHENSIVE APPROACH

\*\*\*\*\*  
DIRECTORATE STAFF  
ASSIGNED: ENVIRONMENT ASSIGNED: Nancy Maynard

ACTION STAFF  
REQUIRED: COMMENTS/CLEARANCE ACTION:

\*\*\*\*\*  
SENDER'S DUE DATE: 01/30/91  
OSTP DUE DATE: 01/30/91 STAFF DUE DATE  
DATE COMPLETED: DATE COMPLETED/DEPT: 01/28/91  
\*\*\*\*\*

COPIES TO: D. Allan Bromley  
Ken Yale

\*\*\*\*\*  
WHITE HOUSE TRACKING #: CONTACT PERSON:  
PHONE: EXT:  
REMARKS: Taken care of Via Staff interaction (DAB is Chairman of the  
Group that put together this report so no formal response is  
necessary) Located in Environemnt Libray

CLOSED

OSTP RECEIVED: 01/28/91 DEPT RECEIVED:  
FILE: P-ENVIRONMENT

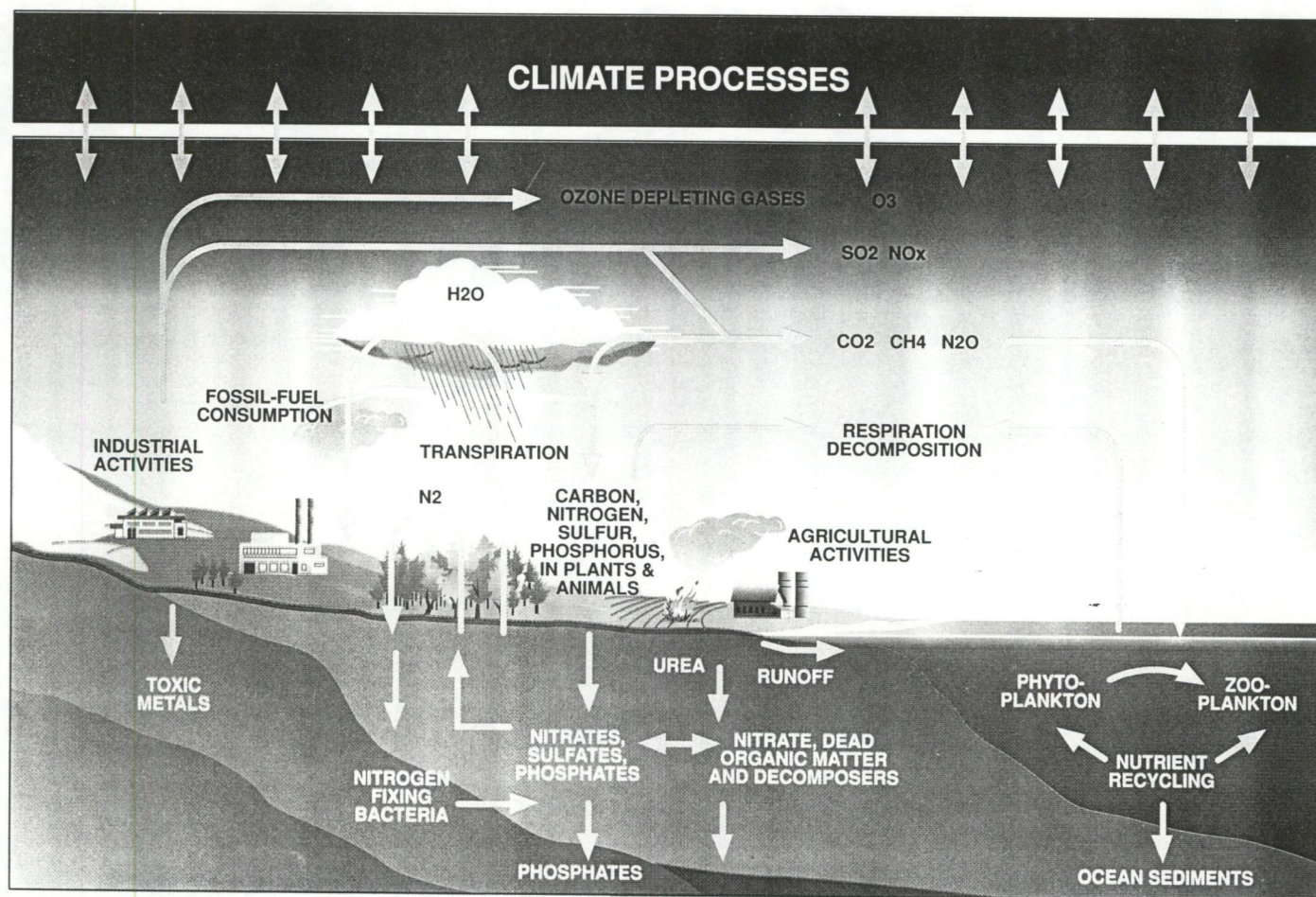
CENTRAL FILES:





# A COMPREHENSIVE APPROACH TO ADDRESSING POTENTIAL CLIMATE CHANGE

*Report of the Task Force on the  
Comprehensive Approach  
to Climate Change*







U.S. Department of Justice

Environment and Natural Resources Division

RECEIVED

91 JAN 28 P12:55

Office of the Assistant Attorney General

Washington, D.C. 20530

January 24, 1991

OFFICE OF THE DIRECTOR

MEMORANDUM

TO: D. Allan Bromley  
Assistant to the President for Science and Technology  
Chair, DPC Global Change Strategy Group

FROM: Dick Stewart *D. Stewart*  
Assistant Attorney General  
Chair, Task Force on Comprehensive and Incentives  
Approaches to Climate Change

SUBJECT: Report on the Comprehensive Approach

Attached for review by the Global Change Strategy Group is the Report of our Task Force, "A Comprehensive Approach to Addressing Potential Climate Change." The PCC Working Group on Climate, led by the State Department, has requested that this Report be available for distribution to foreign governments and other interested persons during the negotiations on a framework convention on climate change starting February 4, 1991.

The Report has been reviewed and cleared through a joint circulation to both our Task Force on the Comprehensive and Incentives Approaches to Climate Change, and the PCC Working Group on Climate. Once cleared by the DPC Global Change Strategy Group, this Report will be distributed to the public. In order to distribute it by the first week of negotiations, February 4, 1991, we will need comments and clearance by no later than **COB Wednesday, January 30, 1991**. Please request that any comments be delivered to Jonathan Wiener at fax 514-0557 or phone 514-2744.

The Report draws on the Task Force's "Interim Report" of November 8, 1990, and on the very large volume of work ongoing by various agencies that supports the Task Force's efforts to define and develop comprehensive and incentives approaches. The "Overview: An Outline of Key Points" is a revised version of the outline circulated December 31 by you for review by the DPC Global Change Strategy Group, incorporating comments received during that review and edits for public release.

It has been suggested that Chapter VIII of the Report be removed because the text on emissions trading, though accurate and in the U.S. interest, might in this context imply a willingness to discuss emissions limitations. We believe this question should be decided by the DPC Global Change Strategy Group.



REVISED DRAFT 1/24/91

**A COMPREHENSIVE APPROACH TO ADDRESSING POTENTIAL CLIMATE CHANGE**

A Report of the Interagency  
Task Force on  
Comprehensive and Incentives Approaches  
to Climate Change

January 1991

U.S. Department of Justice  
Environment & Natural Resources Division  
Washington, D.C.

# A COMPREHENSIVE APPROACH TO ADDRESSING POTENTIAL CLIMATE CHANGE

## A Report of the Interagency Task Force on Comprehensive and Incentives Approaches to Climate Change

### Table of Contents

| <u>Section</u> | <u>Title</u>                                            | <u>Page</u> |
|----------------|---------------------------------------------------------|-------------|
| Overview:      | An Outline of Key Points                                | 1           |
| Chapter I:     | The Setting                                             | 11          |
| Chapter II:    | The Science of Climate Change                           | 16          |
| Chapter III:   | Defining a Comprehensive Approach                       | 30          |
| Chapter IV:    | A Comprehensive Approach to Research<br>and Monitoring  | 39          |
| Chapter V:     | Environmental Advantages of a<br>Comprehensive Approach | 44          |
| Chapter VI:    | Economic and Institutional Flexibility                  | 58          |
| Chapter VII:   | Potential Objections and Replies                        | 69          |
| Chapter VIII:  | Market-Based Incentives                                 | 76          |
| Conclusion:    | Toward a Comprehensive Approach                         | 91          |

---

This Report is the product of an interagency task force of the United States Government. The "Task Force on Comprehensive and Incentive Approaches to Climate Change" was organized in May 1990 to define and develop the comprehensive approach. The Task Force is an interagency effort with representatives of CEA, CEES, CEQ, DOC/NOAA, DOE, DOI, DOJ, DOT, EPA, NASA, NSF, OPD, OSTP, State, USDA, USTR, Treasury, and WH Counsel. It is chaired by the Department of Justice, Environment & Natural Resources Division. Comments on this Report, and requests for additional copies, should be sent to the attention of Jonathan Wiener, Environment and Natural Resources Division, U.S. Department of Justice, Room 2143, 10th & Constitution Avenue, N.W., Washington, D.C. 20530.



A COMPREHENSIVE APPROACH  
TO ADDRESSING POTENTIAL CLIMATE CHANGE

**OVERVIEW: AN OUTLINE OF KEY POINTS**

As negotiations on a Framework Convention on Climate Change begin, it is timely to consider the best approach to addressing potential human-induced global climate change in a convention and in possible subsidiary instruments. We know from experience that the success of environmental policy instruments and institutions is critically related to their design. If law fails to match the environmental system to which it is addressed, the results are frustrating failure and dysfunction. It is crucial that careful attention be given to the question of how best to match the structure and content of any international agreement to the science and economics of human interactions with climate.

The best design for the climate change convention, and for any policy responses, would be a "comprehensive" approach that addresses all relevant trace gases, their sources and sinks. In August 1990, the Intergovernmental Panel on Climate Change (IPCC) included in its Overview the statement: "A comprehensive strategy addressing all aspects of the problem and reflecting environmental, economic and social costs and benefits is necessary." In November 1990, the government ministers at the Second World Climate Conference (SWCC) declared: "We recommend that in the elaboration of response strategies, over time, all greenhouse gases, sources and sinks be considered in the most comprehensive manner possible..."

A comprehensive approach is needed in order to deal with all of the many the scientific, environmental and economic aspects of the climate system, which involves many trace gases affected by activities in every sector of human society. From the point of view of environmental quality, the focus of interest is the combined effect of all the greenhouse gases on the environment. A "piecemeal" approach, focusing narrowly on only one aspect of the system such as one greenhouse gas, would be scientifically inadequate, environmentally ineffective, and economically inefficient. It would repeat the mistakes made in many traditional environmental policies over the last two decades.

In contrast, under a comprehensive approach, all greenhouse gases, their sources and sinks are addressed together. The result is more coherent understanding of the factors contributing to potential global climate change, and more effective and efficient design of any policies to address those



factors. In order to address all greenhouse gases together, a comprehensive approach employs a measure, such as an "index," to compare the contributions of different gases to total global climate change. A comprehensive approach also employs the concept of "net emissions," taking into account the uptake of gases by sinks as well as their release from sources.

A comprehensive approach thus addresses all of the anthropogenic factors contributing to potential climate change. It assembles the elements needed for a full understanding of potential climate change, and helps identify the areas most in need of further research. As we urgently press ahead, through the framework convention, to improve scientific and economic understanding of global change, a comprehensive approach is essential to advancing worldwide knowledge, research, and measurement of the climate system and of human interactions with climate. A comprehensive approach is critical to any effort to forecast the potential for future climate change associated with human emissions of trace gases.

The comprehensive concept is an "approach" or heuristic that offers insight into any discussion of response strategies for potential climate change. The utility of the approach is not limited to the design of emissions limitation policies; it is the proper framework for pursuing scientific research, developing technology, or evaluating current policy actions. It chiefly suggests how to design sound policies, not how much to respond.

In addition, if measures to prevent climate change are warranted, a comprehensive approach would be the most environmentally effective as well as economically efficient design. By addressing all the human-influenced factors in potential global climate change and using an index of relative impacts, a comprehensive approach maximizes the environmental value of every investment in greenhouse abatement. It highlights and avoids the shifts by economic actors from regulated to unregulated activities that will likely occur under narrowly aimed piecemeal policies; these shifts can undercut or even reverse the benefits of the piecemeal measure. The comprehensive approach encourages the use of the most innovative and resource-efficient responses, including efforts to conserve and expand greenhouse gas sinks, such as forests, with related benefits. Furthermore, because each nation has a different economy, society, and portfolio of greenhouse gas sources and sinks, the best set of response measures will be different for each nation; a comprehensive approach provides the needed flexibility for each nation to develop its most cost-effective mix of measures to fit its particular domestic needs while achieving global results.



**"Comprehensive Approach" described**

- o It is an approach to structure consideration of climate change issues -- scientific, economic and policy -- on a comprehensive basis, addressing all the human interactions with the climate system.
- o It stands in contrast to the "piecemeal" approach currently dominating discussion, which focuses narrowly on emissions of one gas, carbon dioxide (CO<sub>2</sub>), primarily from the energy sector, and omits other critical factors.
- o It considers all of the significant human-influenced "radiatively active trace gases" (RATGs) that affect climate:

- Carbon dioxide (CO<sub>2</sub>)
  - Methane (CH<sub>4</sub>)
  - Nitrous oxide (N<sub>2</sub>O)
  - Chlorofluorocarbons (CFCs), Hydrochlorofluorocarbons (HCFCs), and related substances
  - Tropospheric Ozone (O<sub>3</sub>) and its precursors:
    - Nitrogen oxides (NO<sub>x</sub>)
    - Carbon monoxide (CO)
    - Volatile organic compounds (VOCs or NMHCs)

- o It considers all sources and sinks (such as forests and oceans) of the relevant gases, in every sector of human activity:

- Energy production
  - Transportation
  - Agriculture
  - Forestry and land clearing
  - Industry

It focuses on "net emissions" (sources less sinks), the important variable for determining atmospheric concentrations.

- o A comprehensive approach is in use in other areas:
  - The Montreal Protocol's use of an Ozone Depletion Potential (ODP) index to phase out CFCs and related substances
  - "Multimedia" approaches to integrated management of land, air, and water pollution.

### Comparing trace gases

- o A comprehensive approach employs a measure, such as an index, of the comparative environmental impacts of the gases. This index reflects the fact that gases vary in their environmental characteristics:
  1. Heat trapping ability ("radiative forcing")
  2. Residence time in the atmosphere
  3. Reactivity with other gases (affecting both the gas' own residence time and the production of other radiatively active trace gases)
  4. Other attributes, such as ozone depletion or plant fertilization.
- o One possible index is the "Global Warming Potential" (GWP) index of "radiative forcing," presented in the IPCC Report:

| Gas    | Instantaneous<br>radiative forcing<br>per kg (rel. to CO2) | Atmospheric<br>residence years<br>(estimated) | Relative radiative<br>forcing potential<br>over years |            |            |
|--------|------------------------------------------------------------|-----------------------------------------------|-------------------------------------------------------|------------|------------|
|        |                                                            |                                               | <u>20</u>                                             | <u>100</u> | <u>500</u> |
| CO2    | 1                                                          | 120                                           | 1                                                     | 1          | 1          |
| CH4    | 58                                                         | 10                                            | 63                                                    | 21         | 9          |
| N2O    | 206                                                        | 150                                           | 270                                                   | 290        | 190        |
| CFC-11 | 3970                                                       | 60                                            | 4500                                                  | 3500       | 1500       |
| CFC-12 | 5750                                                       | 130                                           | 7100                                                  | 7300       | 4500       |

(Source: IPCC Scientific Assessment, 1990, Tables 2.3, 2.8.)

- o Use of an index provides a guide to environmentally optimal choices, maximizing the environmental value of each investment of society's resources. It also helps ensure that decisions are not made that limit one gas while ignoring and inadvertently increasing others.
- o Use of an index also allows flexibility to design a mix of measures addressing the various gases, toward any overall goal.
- o Some index or weighting system is unavoidable, whether implicit or explicit. A CO2-only policy implicitly weights the other gases at zero.



#### **A Comprehensive Approach has multiple applications**

- Research. Designing research strategies to improve understanding of all relevant gases, sources, sinks, and source/sink processes. Many are not yet sufficiently well understood and require significant study. Development of trace gas indices, and integrated science/economics research, should also be pursued.
- Monitoring and Inventories. Calculating current atmospheric concentrations and net emissions for all relevant gases by nation and sector. Today the ability to measure sources and sinks of several trace gases, such as N<sub>2</sub>O and CH<sub>4</sub>, and to measure sinks of CO<sub>2</sub>, is incomplete.
- "Report cards." Calculating the likely effects of current policy actions on net emissions of all relevant gases. This task depends on reliable forecasts of trace gas emissions trends, which also require a comprehensive approach.
- Technology evaluation. Calculating the effects on net emissions for all gases of technologies and practices. Possible uses in technology transfers, financial assistance, R&D funding.
- Policy choices. Calculating the effects on net emissions of proposed policy actions. The comprehensive approach provides a powerful analytic tool for evaluating piecemeal policy proposals.
- Policy design. Defining any proposed or agreed response measures in terms of a comprehensive approach, accounting for and allowing flexibility among all relevant gases, sources and sinks.

#### **The policy context of a Comprehensive Approach**

- The comprehensive concept is an "approach" or heuristic that offers insight into any discussion of response strategies for potential climate change. The utility of the approach is not limited to the design of emissions limitation policies; it suggests the proper scope and optimal design for pursuing scientific research, developing technology, evaluating current policy actions, or designing emissions limitations policies (whether domestic or international).
- It chiefly considers how to design sound policies, not how much to respond, though it does shed light on the latter question by focusing analysis on the full environmental benefits and economic costs of potential actions.



## Advantages of a Comprehensive Approach

### A. Environmental advantages

- o Piecemeal policies have often proved environmentally ineffective or even counterproductive. Historically, environmental policy design has been piecemeal: efforts have been aimed separately at emissions into the air, water, and land "media." This piecemeal approach has led to "cross-media shifts" in "residuals" (emissions and wastes), moving pollution around without reducing it.
- o Piecemeal pitfalls: shifting residuals in the climate context. A narrow focus on limiting emissions of one trace gas, or one sector, could induce counterproductive shifts in emissions to unregulated gases and sectors. For example:
  - Piecemeal policy aimed at CO<sub>2</sub> alone would induce fuel-switching from coal to natural gas, because natural gas emits less CO<sub>2</sub> per BTU than coal. But a CO<sub>2</sub>-only approach would overlook the resulting increased methane (CH<sub>4</sub>) emissions from leakage of natural gas facilities. At a CH<sub>4</sub> leakage rate of about 6%, roughly all of the CO<sub>2</sub>-related reduction in radiative forcing from the coal-to-gas fuel switch is offset by CH<sub>4</sub> leaks. (Rodhe (1990), using a 100-year GWP; not counting CH<sub>4</sub> venting from fuel extraction.) Since CH<sub>4</sub> leaks are thought to average about 2-4% worldwide, about half the CO<sub>2</sub>-related savings would be offset. And CH<sub>4</sub> leaks may average 5-10% in the Soviet Union, where coal-to-gas switching under a CO<sub>2</sub>-only emissions limitation could actually increase net radiative forcing.  
Moreover, capturing fugitive CH<sub>4</sub> emissions might be a highly cost-effective means of limiting contributions to radiative forcing, especially where leakage rates are high. A CO<sub>2</sub>-only policy ignores that option.
  - Piecemeal focus on limiting agricultural CH<sub>4</sub> from wet rice farming could induce use of nitrogenous fertilizers that reduce CH<sub>4</sub> emissions per rice yield, but also raise N<sub>2</sub>O emissions.
  - Piecemeal focus on a subgroup of emitters, such as only a few nations, would omit major sources of future emissions, and would be undercut by shifts in emissions-intensive activities to other nations.

A comprehensive approach ensures that policy makers are aware of and account for such shifts.



### Advantages, continued

- o Optimal signals. A comprehensive approach would provide optimal incentives in any efforts, if warranted, to develop new technology or limit emissions. It maximizes the environmental benefit from any investment of social resources. It provides an environmentally sound guide to selection of technologies for development and transfer, or to enacting incentive policies, across the entire range of socioeconomic activities affecting trace gas net emissions.
- o Inclusion of Sinks. By focusing on "net" emissions, the comprehensive approach fosters sink protection and expansion, such as afforestation and protection of carbon-fixing phytoplankton. Benefits may include biodiversity, reduced soil erosion, and protected food webs. (Management of sinks is a complex endeavor, and poorly designed sink enhancement policies could have adverse impacts.)

### B. Economic and social advantages

- o Piecemeal approach is economically inefficient. Piecemeal policy would exclude policy options that address other gases, other sources, or sinks, and could achieve the same environmental outcome at less cost. For example, a policy aimed only at energy sector CO<sub>2</sub> would bar potentially less costly yet equally effective abatement options such as enhancement of CO<sub>2</sub> sinks, CH<sub>4</sub> reductions, faster CFC reductions, and attention to CFC-substitutes.
- o Flexibility reduces costs. Because each nation has a different economy, society, and set of sources and sinks, the costs of different options will vary across gases and sectors and across nations. While limiting CO<sub>2</sub> emissions from energy might be best for one nation, limiting CH<sub>4</sub> emissions from waste disposal (or rice or livestock) might be best for another, afforestation best for a third, and reducing tropospheric ozone precursors best for another. Requiring them all to take the same action would impose needless costs. Affording each nation the flexibility to design its best policy mix to address the various gases, sources and sinks helps minimize the economic costs and institutional dislocations of any emissions limitations.
- o Level Playing Field. A piecemeal approach inevitably favors some nations while disproportionately burdening others. For example, a CO<sub>2</sub>-only approach penalizes nations with relatively greater dependence on fossil fuels or fossil fuel revenues. A comprehensive approach provides a "level playing field" across nations, increasing the likelihood of cooperation.



## Potential Objections to a Comprehensive Approach, and Replies

- o "Data and monitoring of sources and sinks are inadequate."
  - Better data and monitoring are being pursued, and this work needs to be accelerated. The convention should advance international cooperation in this effort.
  - Where direct measurement is impractical, carefully chosen proxies or surrogates can be employed.
  - Incentives could spur monitoring improvements, such as offering rewards to those who develop and demonstrate better monitoring techniques.
  - The groundwork needed to flesh out a workable comprehensive approach is very likely to be less costly than the environmental and economic losses due to a piecemeal approach that is ineffective and inflexible.
- o "The Global Warming Potential Index is uncertain."
  - There is emerging international consensus that the scientific fundamentals are sound.
  - Uncertainties will be reduced as methods, data and estimates improve.
  - Absolute precision is not necessary for practical uses.
  - Some weighting system is unavoidable.
- o "Other discrete actions will have already been taken, such as the forthcoming forestry agreement, limits on CFCs in the Montreal Protocol, and limits on VOCs."
  - Integration of prior and current actions into comprehensive approach will be appropriate in any case.
  - Comprehensive approach provides the opportunity for integrating domestic actions that reduce net trace gas emissions but are taken for other reasons.
- o "CFCs should not be included in comprehensive basket."
  - All substances contributing to radiative forcing should be included. For example, CFCs and CFC substitutes (HCFCs, HFCs) may be quite important to radiative forcing. The Montreal Protocol does not account for these impacts.
  - Comprehensive approach would not allow violation of the Montreal Protocol. Reductions more ambitious than required by the Protocol could earn credit.
  - Some nations are doing more to reduce global CFCs than others, and their contribution should be recognized.
  - Existing reservoirs of CFCs are leaking into the atmosphere, but are not covered by the Montreal Protocol. Giving credit for reductions in these CFCs would provide helpful incentives.



## Objections and Replies, continued

- o "A comprehensive approach is complex and unworkable."
  - Experience shows that a comprehensive approach need not be complex or unworkable. The Montreal Protocol successfully employs a multi-gas approach with an ODP index.
  - As experience with traditional environmental issues shows, piecemeal approach means scrambling to redress unintended shifts and dysfunctions.
  - Comprehensive approach eases workability by affording nations needed economic and institutional flexibility.
- o "We can't afford to wait for a comprehensive approach; we need to do what we can now to address CO2."
  - Development of a comprehensive approach does not mean delay. A comprehensive approach can be phased in as other actions (e.g. forestry agreement), and harder-to-monitor sources and sinks, are integrated.
  - But the framework needs to begin as a comprehensive approach; experience shows that once a piecemeal approach is adopted, interests favored by its narrow scope become entrenched and a sound approach is blocked.
  - Given its environmental and economic advantages, taking the time to develop a comprehensive approach is worthwhile. Hasty resort to a piecemeal approach would achieve less overall environmental gain than fashioning a sound comprehensive approach.
  - By sharing burdens on a level playing field, a comprehensive approach eases the route to consensus; a piecemeal approach imposes disproportionate burdens that will generate resistance.
  - A comprehensive approach makes better use of scarce resources. It thus better provides for sustainable development, which requires both effective and efficient policies since environmental protection ultimately depends on the resources that economic growth provides.
  - A comprehensive approach does not prevent action. Nations who wish to limit net emissions of any of the range of trace gases may do so now; indeed taking a comprehensive approach broadens the set of opportunities to address potential climate change.



**Options for Including a Comprehensive Approach in a Framework Convention.** As described earlier, the comprehensive approach has multiple applications. Each could be incorporated into the work of the IPCC, the convention, and any program the convention establishes. For example, the convention could charge the IPCC or other body to coordinate and assess work on the following:

- (1) Research strategy. Pursue integrated scientific and economics research on a comprehensive basis: ensure attention to the sources, sinks, atmospheric properties, and socioeconomic and ecological impacts of all the relevant trace gases.
- (2) Monitoring. Develop techniques and systems for comprehensive source and sink monitoring: cooperative international networks measuring emissions and uptake of all relevant trace gases. Establish centers for data sharing, harmonizing methodologies, R&D on new techniques.
- (3) International inventories. Build the capacity to estimate international net emissions of relevant trace gases: base-line levels and changes due to policy actions. Provide for national reporting, workshops to compare data and methods.
- (4) Indices. Cooperative development and refinement of indices. The IPCC or other expert body could conduct regular assessments and keep policy makers informed of developments.
- (5) Technology evaluation. Employ a comprehensive approach to assess the net emissions impact of any technology transfer and financial assistance activities.

The convention could also:

- (6) Ensure a comprehensive framework for policy. Ensure that any policy discussion, any calls for "national plans," or any limitations obligations (if any, whether now or in the future), are defined in terms of a comprehensive approach. This could be required, or at least endorsed, in the convention.
- (7) Offer incentives through advance assurance. Give advance assurance that current actions will receive "credit" against any future obligations, in accordance with a comprehensive approach. This would help avoid disincentives to taking actions justified on other grounds, which nations may hold in abeyance until credit for them is assured. Actions could include afforestation, energy conservation, and trace gas reductions, and both national and international programs.



## Chapter I: The Setting

Negotiations are beginning on a "framework convention on climate change." Following the report of the Intergovernmental Panel on Climate Change (IPCC) in August 1990, in particular its paper on legal measures, the convention is likely to contain provisions relating to scientific research, monitoring, information exchange, economics research, and other issues of importance to the negotiating parties. At the same time, the IPCC considered, and some have urged, adoption of response measures to mitigate or adapt to potential climate change.

Any analysis of important events and outcomes requires understanding the underlying systems at work and the interrelationship of the variables that make up those systems. One cannot look only at isolated events or outcomes and expect to understand the complex system as a whole. As the conservationist John Muir put it, "when we try to pick out one thing by itself, we find it hitched to everything else in the universe."

Perhaps no problem exemplifies Muir's adage better than what we have come to call "global change." The intricate web of biological, chemical, geologic, anthropogenic, and other processes at work in the earth system cannot be understood by simple reference to one of its myriad component elements. Forecasts of future global change -- such as potential climate change, stratospheric ozone depletion, or changes in the chemical composition of the atmosphere -- necessarily involve an understanding of biogeochemical trends and equilibria, predictions about the enormously diverse socioeconomic activities that might perturb these equilibria, models of the likely resultant physical changes in the earth system, estimates of any eventual impacts on societies and ecosystems, and appreciation of interwoven feedbacks and synergisms.<sup>1</sup>

Several different "radiatively active trace gases" (RATGs)<sup>2</sup> are emitted, removed, and influenced by human

---

<sup>1</sup> See, e.g., J. Smith and D. Tirpak, eds., The Potential Effects of Global Climate Change on the United States (1989), ch. 2.

<sup>2</sup> The term "radiatively active trace gases" (RATGs) refers to the group of substances that trap thermal radiation in the atmosphere, and that interact with other substances in the atmosphere to produce such gases indirectly or to prolong their atmospheric lifetimes. The related term "greenhouse gases" is also used.



activities. Because these gases are "radiatively active," their presence in the atmosphere may tend to raise the atmosphere's average temperature at the Earth's surface, and may thereby change the global climate. The greenhouse gases affected by human activities include carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), halocarbons such as chlorofluorocarbons (CFCs) and related substances (HCFCs, HFCs), and tropospheric ozone (O<sub>3</sub>), whose precursors include oxides of nitrogen (NO<sub>x</sub>), volatile organic compounds (VOCs), and carbon monoxide (CO). Each greenhouse gas is emitted from a variety of sources and each has a different residence time in the atmosphere, a different ability to trap heat, and different potential impacts on the environment.

Policy formulations need to match the underlying ecological systems they address. The optimal design for the climate change convention, and for any policy responses, would be a "comprehensive" approach that addresses all relevant trace gases, their sources and sinks. This approach has been discussed by United States officials in several papers.<sup>3</sup> The international perspective now seems to be broadening to match the ecological reality: integration of physical and social science is making clear that a comprehensive approach to the complex global system is essential, addressing all the relevant trace gases, their sources and sinks. In August the Intergovernmental Panel on Climate Change (IPCC) stated in its Overview: "A comprehensive strategy addresssing all aspects of the problem and reflecting environmental, economic and social costs and benefits is necessary."<sup>4</sup> In November, the government ministers at the Second World Climate Conference (SWCC) declared: "We recommend that in the elaboration of response strategies, over time, all greenhouse gases, sources and sinks be considered in the most comprehensive manner possible..."<sup>5</sup>

In keeping with its commitment to a comprehensive approach, the United States has undertaken a set of policy

---

<sup>3</sup> See U.S. "Concept Paper" submitted to the IPCC, 29 December 1989; U.S. Papers on "U.S. Experience with Comprehensive and Emissions Trading Approaches to Environmental Policy," Informal Seminar for IPCC WGIII officers, Washington, D.C., February 3, 1990; Richard B. Stewart and Jonathan B. Wiener, "A Comprehensive Approach to Climate Change," 1 American Enterprise 75 (November-December 1990); Interagency Task Force, "The Economics of Long-Term Global Climate Change: A Preliminary Assessment," U.S. Department of Energy, OPA, DOE/PE-0096P, September 1990, pp. vii, 21-22.

<sup>4</sup> IPCC Overview, August 1990, p. 14.

<sup>5</sup> Ministerial Declaration of the SWCC, paragraph 14.



measures that together constitute a comprehensive approach, addressing several RATGs, sources and sinks, and will keep U.S. contributions to radiative forcing at 1987 levels through the year 2000. These actions are shown in Table 1 below. Several other nations have also endorsed or proposed following a comprehensive approach.<sup>6</sup> Because each nation has a different economy, society, and portfolio of greenhouse gas sources and sinks, the best set of response measures will be different for each nation; a comprehensive approach provides flexibility for each nation to develop its most cost-effective mix of measures to fit its particular domestic needs while achieving global results.

If the international response to potential climate change is to be scientifically, environmentally and economically sound, it needs to take a comprehensive approach. Yet all too often, policy discussions zero in hastily on only one of many variables, in spite of our experience that narrow policies addressing only one attribute of a complex system typically provide little or no environmental benefit and incur significant cost. Where the understanding of the environmental system is highly incomplete, hasty adoption of policy measures may apply leverage to the wrong variables, missing or even exacerbating the true problem. In the current discussion, policy commentators initially gravitated to a narrow focus on one aspect of the issue: the potential global warming effects of carbon dioxide (CO<sub>2</sub>) emissions from energy sector activities. This piecemeal approach ignores all the other aspects of climate change, including the several other RATGs, their diverse sources and sinks in all sectors of human activity, and their multiple environmental attributes. The result is a policy thrust that omits most of the science and neglects the foundations of effective policy.

The challenge to those who seek a sound approach to addressing potential climate change is to reorient the discussion to the environmental system and its comprehensive character.

---

<sup>6</sup> See Canada's Green Plan (1990), pp. 97-108. Canada proposes actions on several RATGs in several sectors, and terms the strategy a "comprehensive response," *id.* p. 102. Other nations have announced proposals that address not only CO<sub>2</sub> but also other RATGs. See "Climate Change Policy in the Netherlands and Supporting Measures," Netherlands Ministry of Housing, Physical Planning and the Environment, D.G. for Environment, November 1990 (addressing CO<sub>2</sub> sources and sinks, CFCs, and CH<sub>4</sub>); "Protecting the Earth's Atmosphere," Report of the Federal Cabinet Study Commission, Bonn, Germany, November 7, 1990 (addressing CO<sub>2</sub> and CH<sub>4</sub>); "Action Program to Arrest Global Warming," Decision made by the Council of Ministers for Global Environmental Conservation, Government of Japan, October 23, 1990 (addressing CO<sub>2</sub> sources and sinks, CH<sub>4</sub>, N<sub>2</sub>O).



Table 1.A

**Emissions Reductions Expected in the Year 2000  
Due to Current Environmental Commitments**

| <u>Current Commitment<br/>(with RATG affected)</u>         | <u>Millions of Tons of<br/>Carbon-Equivalents Reduced<br/>through 2000</u> |
|------------------------------------------------------------|----------------------------------------------------------------------------|
| Tree Planting Initiative (CO <sub>2</sub> )                | 9                                                                          |
| DOE Energy Efficiency Initiatives (CO <sub>2</sub> )       | 28                                                                         |
| DOE Appliance Standards (CO <sub>2</sub> )                 | 4                                                                          |
| DOE Renewables Initiatives (CO <sub>2</sub> )              | 4                                                                          |
| 1990 Clean Air Act                                         |                                                                            |
| Acid deposition provision (CO <sub>2</sub> ) <sup>7</sup>  | 17                                                                         |
| Other provisions (NO <sub>x</sub> , CO, VOCs) <sup>8</sup> | 51                                                                         |
| EPA Landfill Regulation (VOCs, CH <sub>4</sub> )           | 44                                                                         |
| CFC Phaseout (CFCs) <sup>9</sup>                           | 551                                                                        |
| <u>Total Reduction from 2000 Trend</u>                     | <u>657</u>                                                                 |

Source: Alex Cristofaro and Joel Scheraga, "Policy Implications of a Comprehensive Greenhouse Gas Budget," U.S. EPA, OPPE, draft September 1990, Table 2. Calculations use the IPCC 100-year radiative forcing ("GWP") index.

<sup>7</sup> The 1990 Clean Air Act will achieve 16.4 million of the 17 million tons of CO<sub>2</sub> reduced through the incentives for energy conservation provided to electric utilities by the innovative emissions trading system the Administration created to reduce acid deposition precursors.

<sup>8</sup> The Clean Air Act will also achieve reductions of 51 million tons of carbon equivalent reductions in NO<sub>x</sub>, CO, and VOCs, especially through restrictions on mobile source emissions.

<sup>9</sup> The figure includes only actions pursuant to the 1987 Montreal Protocol's 50% CFC phaseout; it does not take into account additional reductions the U.S. will achieve under the 1990 London update to a 100% phaseout.



Table 1.B

**U.S. Emissions**  
(Million tons of carbon-equivalent)

| <u>RATG</u>   | <u>1987</u> | <u>2000, without<br/>Current Commitments</u> | <u>2000, with<br/>Current Commitments</u> |
|---------------|-------------|----------------------------------------------|-------------------------------------------|
| CO2           | 1310        | 1565                                         | 1503                                      |
| CH4           | 234         | 252                                          | 208                                       |
| VOCs          | 72          | 72                                           | 48                                        |
| NOx           | 218         | 218                                          | 199                                       |
| CO            | 52          | 52                                           | 45                                        |
| N2O           | 74          | 74                                           | 74                                        |
| CFCs          | 367         | 807                                          | 256                                       |
| <u>Total:</u> | <u>2328</u> | <u>3040</u>                                  | <u>2332</u>                               |

Source: Alex Cristofaro and Joel Scheraga, "Policy Implications of a Comprehensive Greenhouse Gas Budget," U.S. EPA, OPPE, draft September 1990, Figures 4-5. Calculations use the IPCC 100-year radiative forcing ("GWP") index.



## Chapter II: The Science of Climate Change

Several different "radiatively active trace gases" (RATGs)<sup>10</sup> are emitted, removed, and influenced by human activities. Because these trace gases are "radiatively active," their presence in the atmosphere may tend to raise the atmosphere's average temperature at the Earth's surface, and may thereby change the global climate.<sup>11</sup> The RATGs affected by human activities include carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), halocarbons such as chlorofluorocarbons (CFCs) and related substances (HCFCs, HFCs), and tropospheric ozone (O<sub>3</sub>), whose precursors include oxides of nitrogen (NO<sub>x</sub>), volatile organic compounds (VOCs), and carbon monoxide (CO).<sup>12</sup> Each RATG is emitted from a variety of sources and each has a different residence time in the atmosphere, a different ability to trap heat, and different potential impacts on the environment.

From the point of view of environmental quality, the focus of interest is the combined effect of all the RATGs. Assessing the combined effect of trace gases requires an understanding of their varied characteristics. RATGs vary by several characteristics:

1. Heat trapping ability ("radiative forcing")
2. Residence time in the atmosphere
3. Reactivity with other gases (which affects both the gas' own residence time and the production of other radiatively active trace gases in the atmosphere)
4. Other attributes, such as other effects on the environment

---

<sup>10</sup>The term "radiatively active trace gases" (RATGs) refers to substances that, when present in the atmosphere, act to trap thermal radiation; and to other substances that interact in the atmosphere to produce such greenhouse gases indirectly or to prolong their atmospheric lifetimes.

<sup>11</sup>The term "potential global climate change" refers to possible changes in global and regional climate that may result from changes in the atmosphere's thermal radiation budget.

<sup>12</sup>Other RATGs affect the radiative balance of the atmosphere, but unlike GHGs, their main influence is not through absorption of energy reradiated from the Earth's surface. RATGs include aerosol particulates such as sulfur dioxide (SO<sub>2</sub>), which can reflect insolation and thus may exert a net cooling influence. A fully comprehensive approach would encompass all such RATGs.



### RATGs and radiative forcing

RATG molecules affect the radiative balance of the atmosphere, tending to trap heat and warm the Earth's surface. But RATGs do not all have the same impact on atmospheric warming: different molecules absorb thermal radiation at different efficiencies. That is, a molecule of CO<sub>2</sub> has a different potential for "radiative forcing" than a molecule of, say, N<sub>2</sub>O. Estimates of this "instantaneous radiative forcing" impact are shown in the first column of Table 2. Estimating the instantaneous radiative forcing abilities of different trace gas molecules is generally a straightforward matter of laboratory research, and there is high confidence in these numbers. Certain complications arise due to the fact that the forcing effect is dependent on the ambient concentration: as the existing concentration of the gas in question rises, additional molecules add less and less to total radiative forcing. Thus, estimates of the instantaneous radiative forcing of a molecule (or kilogram) can be obtained given knowledge about the concentration of the gas; the estimates presented in the first column of Table 2 are for current concentrations. These estimates show that CO<sub>2</sub> is the weakest of the RATGs, unit-for-unit, at trapping thermal radiation at a given instant in time: CH<sub>4</sub> is 58 times more effective than CO<sub>2</sub>, N<sub>2</sub>O is about 200 times more effective, and CFC-11 and CFC-12 are from 4000 to 6000 times more effective.

The atmospheric residence time of RATGs also varies. Different trace gases remain in the atmosphere for different periods of time. Their "atmospheric lifetimes" or "residence times" depend on such variables as the rates at which they react with other gases in the atmosphere, and the rates at which they are removed by sinks. The prediction of the atmospheric lifetime of a trace gas is thus a mathematical function that depends, among other things, on the atmospheric concentration of relevant gases in the atmosphere, reaction rates in the atmosphere, and sink removal rates. The concentration of gases in the atmosphere depends, in turn, on such variables as the emissions rates, existing concentrations, reactions, and sink removal rates for those gases. Estimates of typical lifetimes, assuming current levels of relevant variables, are shown in the second column of Table 2. These estimates are subject to uncertainties, chiefly because the sink removal processes are not all well understood. For example, each CO<sub>2</sub> molecule cycles in and out of the atmosphere every 5-10 years, but is not finally removed from the atmosphere and deposited in the deep ocean for several hundred years; the "120 years" figure in Table 2 is a current best



estimate, but may change as the ocean-atmosphere carbon cycle is better understood.<sup>13</sup>

The reactivity of RATGs varies as well. Reactions are important sinks for RATGs, because as the molecules react they are broken apart and their atoms combined into new compounds. Some gases, such as N<sub>2</sub>O, are fairly stable, and do not react much with other gases in the atmosphere. In contrast, CH<sub>4</sub>, CO, VOCs, and HCFCs are all highly interactive. They often react with the hydroxyl (OH) radicals that abound in the lower atmosphere, indirectly affecting the abundance of other gases that would otherwise have reacted with the OH radicals. The presence of NO<sub>x</sub> accelerates the formation of tropospheric ozone (O<sub>3</sub>) from CO and VOCs; O<sub>3</sub> is itself a RATG. These kinds of "indirect" effects are included in the cumulative radiative forcing estimates shown in Table 2.

Scientists attempting to judge the cumulative radiative impact of each additional molecule added to the atmospheric concentration of a trace gas must take into account the instantaneous radiative forcing potential of the gas, its likely lifetime in the atmosphere, and its interactions with other gases. The calculation of the cumulative contribution to radiative forcing of each additional molecule over its lifetime can be complicated. Nevertheless recent attempts to calculate the different cumulative contributions of various RATGs, using the "global warming potential" (GWP) method of mathematically integrating the instantaneous radiative forcing of the gas over its probable lifetime, have reached fairly similar results.<sup>14</sup> Table 2 presents the IPCC's estimates of relative radiative forcing per unit mass (kilogram) of each gas emitted, based on the GWP method.

---

<sup>13</sup> The lifetime of gases also may have independent policy relevance because it affects the irreversibility of emissions, the ability to "back out" of unexpected difficulties. An erroneous underestimate of the severity of climate change may be harder to reverse if gases being emitted are long-lived than if they are short-lived.

<sup>14</sup> See, e.g., IPCC Scientific Assessment (1990), Chapter 2; Daniel Lashof and Dilip Ahuja, "Relative Global Warming Potentials of Greenhouse Gas Emissions," 344 *Nature* 529 (April 5, 1990); Thomas Levander, "The Importance of Greenhouse Gases other than Carbon Dioxide and Other Possible Differences Between Various Fuels," Swedish National Energy Administration (Heat & Electricity Production Div.) memorandum Sept. 14, 1989, presented to the OECD Group on Energy and Environment, Oct. 13, 1989.



Table 2

IPCC "Global Warming Potential" (GWP) Indices

| <u>Gas</u> | <u>Instantaneous<br/>radiative forcing<br/>per kg (rel. to CO2)</u> | <u>Atmospheric<br/>residence years<br/>(estimated)</u> | <u>Relative radiative<br/>forcing potential<br/>over years</u> |            |            |
|------------|---------------------------------------------------------------------|--------------------------------------------------------|----------------------------------------------------------------|------------|------------|
|            |                                                                     |                                                        | <u>20</u>                                                      | <u>100</u> | <u>500</u> |
| CO2        | 1                                                                   | 120                                                    | 1                                                              | 1          | 1          |
| CH4        | 58                                                                  | 10                                                     | 63                                                             | 21         | 9          |
| N2O        | 206                                                                 | 150                                                    | 270                                                            | 290        | 190        |
| CFC-11     | 3970                                                                | 60                                                     | 4500                                                           | 3500       | 1500       |
| CFC-12     | 5750                                                                | 130                                                    | 7100                                                           | 7300       | 4500       |
| HCFC-22    | 5440                                                                | 15                                                     | 4100                                                           | 1500       | 510        |
| HFC-134a   | 4130                                                                | 16                                                     | 3200                                                           | 1200       | 420        |

(Source: IPCC Scientific Assessment, 1990, Tables 2.3, 2.8.)



Preliminary calculations with another method, employing large climate models to test the relative effect of a change in each gas on the realised temperature projected by the models, yield index values for other RATGs relative to CO<sub>2</sub>, over a 100-year time horizon, that are roughly twice as large as the GWP method generates.<sup>15</sup> In other words, this method shows CO<sub>2</sub> to be roughly half as important relative to the other RATGs as the IPCC GWP estimates (over 100 years). The differences between the climate model approach and the GWP calculation arise in part because the climate model approach calculated realised temperature change while the GWP calculated equilibrium temperature change, so the two measures may be useful for different purposes. Moreover, while the GWP method assumes possibly simplified dissipation functions and does not depict synergistic effects of multiple forcing agents, the climate models carry many other uncertainties (e.g. the crude or incomplete coupling or atmosphere, oceans, and land, or the limited ability to model cloudiness) that may affect their accuracy.

In any event, all of these studies make it clear that, even taking into account the potentially long atmospheric lifetime of CO<sub>2</sub> molecules, CO<sub>2</sub> has the least impact per unit on atmospheric radiative forcing: it is the weakest RATG. When one looks only at current human contributions to potential atmospheric warming, the effects of CO<sub>2</sub> appear to be large because the volume of CO<sub>2</sub> concentration and emissions is large compared to other anthropogenic trace gases. Assessments of the total contribution from each trace gas to changes in total atmospheric radiative forcing have estimated that CO<sub>2</sub> is responsible for roughly one half of current anthropogenic contributions, while other trace gases account for the remainder.<sup>16</sup> But because the concentrations of most other trace gases are growing more rapidly than those of CO<sub>2</sub>,<sup>17</sup> and because of the relatively larger cumulative impact per molecule of other

---

<sup>15</sup> T.M.L. Wigley, M.K. Hulme, and T. Holt, "An Alternative Approach to Calculating Global Warming Potentials," Climate Research Unit, University of East Anglia, Norwich UK (draft November 1990).

<sup>16</sup> See IPCC Scientific Assessment (1990), Policy makers Summary, p. xx; U.S. Environmental Protection Agency, "The Potential Effects of Global Climate Change on the United States," Report to Congress, Dec. 1989, pp. 12-15 and Figure 2-4.

<sup>17</sup> See U.S. Environmental Protection Agency, "The Potential Effects of Global Climate Change on the United States," Report to Congress, Dec. 1989, pp. 12-15 and Table 2-1.



trace gases relative to CO<sub>2</sub> (as described above), the relative contribution of CO<sub>2</sub> to total atmospheric radiative forcing has declined since 1880.<sup>18</sup> Looking ahead, policy measures would have to address future increments of RATG emissions, so the environmental impact of each additional molecule is necessarily of primary concern.

#### Developing the radiative forcing indices

The time horizons used in the IPCC index -- 20, 100, and 500 years -- define the time over which one considers the impacts of radiative forcing. It is not clear which of these three time slices, or others, is appropriate for making decisions about potential climate change. Would the impacts of one unit of atmospheric warming be worse now, or in 2100, or in 2600? Given possible advances in technology and knowledge, and other potential changes in the environment, it is virtually impossible to predict what the impact of warming might be 500 years from now, and so one might decide to ignore radiative forcing effects beyond, say, 100 years. On the other hand, it is possible that distant future warming will burden an already increasingly stressed planet, and hence be more damaging. Put another way, what is the value to present persons of avoiding a unit of warming now, versus a unit of warming 100 years from now? At what rate might we "discount" future warming, as a proxy for discounting the future adverse impacts of warming? Adopting a shorter time horizon has the same effect as adopting a higher discount rate: future effects are deemed less worrisome than near-term effects. A simple linear extrapolation of the effects of warming over time is probably not exactly accurate,<sup>19</sup> yet it is hard to tell today how else to estimate the importance of future radiative forcing. Every calculation of a radiative forcing index has used some form of weighting present and future effects.<sup>20</sup>

---

<sup>18</sup>See U.S. Environmental Protection Agency, "The Potential Effects of Global Climate Change on the United States," Report to Congress, Dec. 1989, p. 15, Figure 2-4. Because of the imminent phaseout of CFCs, which represented 15-20% of radiative forcing in the 1980s, CO<sub>2</sub>'s relative share of radiative forcing is predicted to be stable or increase in the future.

<sup>19</sup> See Richard Eckaus, "Comparing the Effects of Greenhouse Gas Emissions on Global Warming," MIT Center for Energy Policy Research, November 1990.

<sup>20</sup> The IPCC uses time horizons. Lashof & Ahuja, supra use a discount rate.



Other improvements could be made in the radiative forcing index. Work is needed to harmonize various quantitative approaches and extend international understanding of indices, and to improve the accuracy of estimated residence times of RATGs. Scientific uncertainties in the current estimates remain surrounding the residence time of CO<sub>2</sub>, due to complications in the carbon cycle and uncertainties in CO<sub>2</sub> sink removal processes. Atmospheric chemical reactions involving other gases, such as CH<sub>4</sub> and precursors to tropospheric O<sub>3</sub>, complicate estimates of their residence times. Recent work at the National Oceanic & Atmospheric Administration (NOAA) laboratories is substantially improving estimates of the dissipation rate and residence time of CH<sub>4</sub> (which now appear to be longer than previously thought, thus raising the relative GWP of CH<sub>4</sub>). As work on indices is ongoing, uncertainties in best estimates can be expressed and revised.

The indirect effects attributable to various gases' atmospheric reactions also need additional analysis. Certain trace gases react to form other radiatively important trace gases, or react with substances that would otherwise affect RATG abundances. These effects may be especially important for CH<sub>4</sub> and HCFCs. Another step to be taken is modeling index values as they are affected by "saturation" effects: as concentrations of gases grow, the band of the electromagnetic spectrum blocked by a gas may become occluded so that additional increments of the gas have diminishing marginal radiative forcing impacts. Current radiative forcing estimates could be revised to account for these diminishing potencies in future years with higher concentrations. And estimates need to take account of the implications that vertical and other distribution of RATGs in the atmosphere may have for calculated index values. Most generally, institutional mechanisms for developing a consensus index and adjusting it to new research results need to be developed. The framework convention could spur the formation or nomination of such institutions.

Although these uncertainties remain in the GWP values, the consensus of the IPCC was that the scientific method of calculating GWPs is sufficiently sound to permit its use. Similarly, an international workshop on GWP Indices organized by NOAA, EPA, NASA, UKDOE and others in Boulder, Colorado in November 1990, concluded that though these uncertainties require urgent attention, they do not undermine the scientific fundamentals of the GWP index and do not warrant abandoning it. For practical policy purposes, some weighting system is unavoidable: not using an explicit index means weighting other gases at zero, or haphazardly. A fairly good index, appropriately employed, is a great deal better than no index at all. A good but imperfect index could serve well and then be amended later when knowledge improves.



More complete indices: toward a "global change index"

RATGs also have other environmental impacts, but these characteristics are not accounted for in the radiative forcing index. Radiative forcing is only an intermediate physical effect of trace gases, and is really a proxy used as a common metric to compare the diverse RATGs.<sup>21</sup> But RATGs have multiple attributes of societal and ecological concern; they yield other, non-warming environmental impacts of global and local significance which may be more important (in magnitude, timing, or other features) than their contributions to radiative forcing. For example, CO, NOx, urban O3, and SO2 are reactive and/or toxic. CFCs and related substances deplete the stratospheric ozone layer. Higher CO2 concentrations increase plant photosynthesis and increase plants' water use efficiency,<sup>22</sup> increasing crop yields and improving their drought-resistance.

Accurate understanding of the environment that will prevail in a world of higher RATG concentrations, as well as the optimal design of incentives for policy choices, would entail developing a comparative index that incorporates the full externalities (social and ecological costs) imposed by increments of each RATG.<sup>23</sup> And it might try to take account of the variations in the cost of warming incurred at different times and different places.<sup>24</sup> Without a more "complete" index, a simple radiative forcing index could provide signals or incentives that yield desirable changes in aggregate radiative forcing but undesirable changes in other impacts; in economists' words, significant externalities will remain uninternalized, and the incentive signals of the narrow index may produce perverse

---

<sup>21</sup>Measurement of the ultimate impacts of warming itself on biological and other systems, though critical for assessing the costs and benefits of climate change, are not generally incorporated into the radiative forcing index because such impacts stem from warming generically, and are not expected to vary depending on the type of gas enhancing the warming.

<sup>22</sup> See Norman Rosenberg, et al., "From Climate and CO2 Enrichment to Evapotranspiration," in Paul Waggoner, ed., Climate Change and U.S. Water Resources (1990), pp. 151-75.

<sup>23</sup> See John Reilly, "Climate Change Damage and the Trace Gas Index Issue," USDA, Economic Research Service, draft November 1, 1990.

<sup>24</sup> See Richard Eckaus, "Comparing the Effects of Greenhouse Gas Emissions on Global Warming," MIT Center for Energy Policy Research, November 1990.



outcomes. Efforts to limit warming that totally ignored other consequences might generate unacceptable increases in ozone depletion or toxic air pollutants, or deprive crops of needed atmospheric carbon.

For example, if only CO<sub>2</sub> concentrations double over the next several decades, climate-induced crop yield losses may be largely offset by the positive yield effects due to CO<sub>2</sub>'s "fertilization" and water use efficiency effects on plants. If equivalent RATG doubling were, however, due completely to gases other than CO<sub>2</sub>, then these positive offsets would not be realized. And if the RATG increase were made up of gases with other harmful effects, such as CFCs or very large quantities of CFC substitutes that still deplete the ozone layer, there would be additional negative consequences besides warming. The upshot is that society should be interested in focusing any control efforts where they will do the most good, considering all environmental impacts.

Crafting a "complete" index of ultimate costs poses quite difficult analytic and technical problems. Data are not yet adequate on important aspects of the magnitude and variations of the diverse impacts; for example, data are lacking on the effects of ozone depletion on UV-B irradiance, and on the effects of changes in UV-B irradiance on biota. Comparing the dissimilar warming and non-warming impacts on a common scale, something like comparing apples and oranges, is a challenge requiring serious analytic efforts. Predicting economic effects far into the future is, as noted earlier, a highly inexact science.

A somewhat more realistically achievable index would incorporate only the key "global change" attributes of each RATG, namely their radiative forcing and the other salient non-warming global impacts of RATGs, such as the direct effects of CO<sub>2</sub> enrichment and the ozone depletion impacts associated with CFCs and other halocarbons.<sup>25</sup> The diverse global impacts of the gases would be estimated using best economic forecasting tools, coupled with expert evaluations of the ecological impacts and of the relative importance of the diverse impacts. This "global change index" would thus be an improved, albeit still incomplete, proxy for ultimate economic and ecological damages. It would capture the main global externalities associated with the gases, providing significantly better policy signals than an index limited to radiative forcing. It would nonetheless require effort and time to construct; the global change index should therefore be developed as a complement to and in tandem with the more technically manageable radiative forcing index.

---

<sup>25</sup> Essentially local attributes of the gases, such as their toxicity, would be left to local policy strategies.



A very preliminary estimate has been made of a somewhat more complete index of global environmental impacts. By incorporating the incremental impact of RATGs due to only two effects -- radiative forcing and CO2 enrichment of agriculture -- one study has estimated the following index values:

Table 3

**Comparisons of Trace Gas Indices**

| <u>RATG</u> | Physical Effects:<br>Instantaneous<br><u>Radiative Forcing</u> | Economic Impacts:<br>Climate Effects<br><u>+ CO2 Fertilization</u> |
|-------------|----------------------------------------------------------------|--------------------------------------------------------------------|
| CO2         | 1                                                              | 1                                                                  |
| CH4         | 58                                                             | 92                                                                 |
| N2O         | 206                                                            | 260                                                                |
| CFC-11      | 3970                                                           | 6343                                                               |
| CFC-12      | 5750                                                           | 9119                                                               |

Source: From John Reilly, "Climate Change Damage and the Trace Gas Index Issue," USDA, Economic Research Service, draft November 1, 1990, Table 3.

The "instantaneous radiative forcing" index values in column 1 are simply taken from the IPCC, as shown above in Table 2. The estimates in column 2 of the economic effects of climate change -- due to radiative forcing and CO2 fertilization of crops -- are derived by computing the effects of radiative forcing in climate forecasting models, and using estimates of future economic and environmental impacts under different climate and CO2 regimes to estimate net economic impacts. Both the climatological and the economic forecasting models are subject to significant uncertainties, so the economic impacts index shown above is necessarily uncertain. In addition, the index computed here only accounts for the economic impacts of warming and CO2 fertilization on global agriculture, omitting effects on other sectors and on ecosystems.<sup>26</sup>

Nevertheless, the index in Table 3 suggests the great importance of the non-warming impacts of the RATGs. It suggests that a unit of social resources expended to limit emissions of CH4 generates about 90 times more benefit than the same unit of

---

<sup>26</sup> In addition, Reilly's economic effects index does not account for the depletion of stratospheric ozone due to CFCs, which would markedly increase CFCs' index values (assuming ozone depletion is highly damaging to humans and the environment). Nor does it account for the local toxicity of certain RATGs.



resources spent to limit CO<sub>2</sub> -- rather than roughly 60 when considering only radiative forcing. It thus suggests that counting radiative forcing alone leads to an substantial underestimate (by about a third) of the value of controlling CH<sub>4</sub> relative to CO<sub>2</sub>, and likewise a substantial overstatement of the value of controlling CO<sub>2</sub> relative to CH<sub>4</sub>. Similar comparisons may be made for the other trace gases. And because the index shown in Table 3 does not account for the ozone-depleting effects of CFCs, a more complete index incorporating those serious environmental impacts would raise the CFC figures further, probably well above the 6300 and 9000 figures shown here; in other words, the relative benefit of controlling CFCs is still understated in this index.

#### Policy implications of RATG science

These scientific observations lead to the conclusion that any sound effort to address potential global climate change must address all relevant trace gases, and treat them in accordance with their different environmental impacts. Considering both radiative forcing potential, of which CO<sub>2</sub> is the least potent anthropogenic agent, and the non-warming impacts of the RATGs, it is clear that unit-for-unit, CO<sub>2</sub> is the most environmentally benign of the RATGs. If society and the biosphere had to accept any given amount of predicted warming, then on purely environmental grounds (abstracting from the costs of limitation strategies), it would prefer to have as much of that given amount of warming due to CO<sub>2</sub> and as little due to other RATGs.

At the same time, the lifetime of gases has independent policy relevance because it affects the irreversibility of emissions, that is, the ability to "back out" of unexpected difficulties. An erroneous underestimate of the severity of climate change is harder to reverse if gases being emitted are long-lived than if they are short-lived.<sup>27</sup> Thus, while the residence time is already incorporated in measures such as the GWP index, it has additional importance where the ultimate impact of radiative forcing is highly uncertain.

Whether the goal is to understand, predict, or limit potential atmospheric warming, attention must be paid to all the gases contributing to that result. Predicting radiative forcing without good data on the RATGs other than CO<sub>2</sub> would clearly be unsatisfactory, as elaborated in Chapter IV. An understanding of the relative contributions of different trace gases to potential

---

<sup>27</sup> On the other hand, if for some reason it later turns out that warming is desirable but difficult to generate quickly, it might be better to have emitted more long-lived RATGs.



atmospheric warming (and other environmental impacts) is a prerequisite for setting a research agenda and for assessing the costs and benefits of different policy responses. Placing limits on emissions of just one gas would leave other gases unrestricted; this problem is discussed further in Chapter V. And limiting emissions of certain gases may be less costly to society (or to different nations or sectors of society), or more beneficial to the environment, than limiting others; this topic is taken up in Chapter VI.

#### Diverse sources and sinks

Similarly, the scientific nature of how RATGs enter and leave the atmosphere indicates that attention should be paid to the full range of their sources and sinks. Trace gases are generated by numerous sources, including human ("anthropogenic") activities, other biological activities, and non-biological processes. Among the anthropogenic sources of trace gases are virtually every sector of human activity, including mining, energy generation, transportation, agriculture, forestry, waste disposal, industry, building and residential services, and others. Biogenic sources are similarly diverse. The full range of sources deserves attention in developing effective response strategies.

Meanwhile, some gases are removed from the atmosphere by "sinks" such as trees, phytoplankton, ocean mixing, and chemical reactions. Whether the goal is to predict or limit emissions of RATGs, contraction and expansion of sinks is an important component. Sink conservation and expansion might achieve net emissions limits at potentially lower cost per molecule than restrictions on some sources of trace gases. Moreover, expanding sinks such as forests can have other important environmental and economic benefits, such as protection of biodiversity and soil conservation. If response strategies are to address the possible causal factors of potential global climate change, the variety of both sources and sinks of trace gases must be included.

Examples of the sources and sinks of each of several RATGs are presented in Table 4. Other sources and sinks not affected by human activity have been omitted from the Table, such as photochemical destruction of N<sub>2</sub>O in the upper atmosphere. The enormously diverse set of sources and sinks shows the pervasive and complex web of human activities that affect RATG concentrations. This is both an opportunity and a challenge: an opportunity to understand the full set of human interactions that may contribute to climate change, and a challenge to avoid focusing narrowly on one source or sink while ignoring others. As Chapter V explains in greater detail, the interconnected web of human activities worldwide that affect RATG emissions makes



narrow policies inappropriate: narrow regulations are likely to be undermined as economic actors shift away from regulated sources toward unregulated ones.

For certain of the sources and sinks listed in Table 4, data and models are not yet sufficient to quantify their contributions to net emissions. As Chapter IV describes, a critical goal of the framework convention and other efforts should be to improve understanding and measurement of these sources and sinks.



Table 4  
Selected Sources & Sinks Subject to Human Influence

| <u>Gas</u>                                   | <u>Sources</u>                                                                                                                                                           | <u>Sinks</u>                                            |
|----------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|
| Carbon dioxide<br>(CO <sub>2</sub> )         | Fossil fuel combustion<br>Land clearing<br>Biomass combustion                                                                                                            | Forests<br>Grasses<br>Soils<br>Ocean biota<br>& storage |
| Methane<br>(CH <sub>4</sub> )                | Livestock: enteric fermentation, wastes<br>Rice cultivation<br>Wetlands<br>Landfills<br>Natural gas drilling, venting, transmission<br>Coal mining<br>Biomass combustion | Atmospheric OH interaction<br>Soil removal              |
| Nitrous oxide<br>(N <sub>2</sub> O)          | Agricultural fertilizers<br>Land clearing<br>Biomass combustion                                                                                                          | Soil removal                                            |
| Halocarbons<br>(CFCs and related)            | Refrigerants<br>Aerosol propellants<br>Foam blowing agents<br>Solvents and cleaning agents<br>Fire retardants                                                            | Recapturing and destroying existing supplies            |
| Tropospheric Ozone<br>(O <sub>3</sub> )      | Precursors: CH <sub>4</sub> , CO, VOCs, in the presence of NO <sub>x</sub><br>Transport of strat. O <sub>3</sub> into troposphere                                        | Halocarbon depletion                                    |
| Carbon monoxide<br>(CO)                      | Fossil fuel combustion<br>Biomass combustion<br>Precursors: CH <sub>4</sub> , VOCs                                                                                       | Atmospheric OH interaction                              |
| Nitrogen Oxides<br>(NO <sub>x</sub> )        | Fossil fuel combustion<br>Biomass combustion<br>Agriculture                                                                                                              |                                                         |
| Volatile Organic Compounds<br>(VOCs)         | Fossil fuel combustion<br>Biomass combustion<br>Industrial processes                                                                                                     | Atmospheric OH interaction                              |
| Aerosols/sulfates<br>(e.g. SO <sub>2</sub> ) | Fossil fuel combustion                                                                                                                                                   |                                                         |



### Chapter III: Defining a Comprehensive Approach

#### A. Description of the comprehensive approach.

The "comprehensive" approach seeks to address all the important contributors to potential climate change, in contrast to a piecemeal focus on CO<sub>2</sub> from the energy sector. It therefore addresses all radiatively active trace gases (RATGs), their sources and sinks. RATGs include carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), halocarbons such as chloro-fluorocarbons (CFCs) and related substances (HCFCs, HFCs), and tropospheric ozone (O<sub>3</sub>), whose precursors include oxides of nitrogen (NO<sub>x</sub>), volatile organic compounds (VOCs), and carbon monoxide (CO).<sup>28</sup> Different RATGs arise from different sources<sup>29</sup> and are removed from the atmosphere by different sinks,<sup>30</sup> yielding a "net emissions" budget.

Different RATGs have different impacts on the environment; for example, each gas has a different ability to alter the earth's heat balance by trapping certain radiated energy (or reflecting it). This influence on the earth's thermal balance, referred to as "radiative forcing," is described in Chapter III. In order to relate the comparative environmental impacts of the various RATGs, the comprehensive approach employs a parameter or "index" that calculates the relative environmental impact of each gas. One basis for such an index is the

---

<sup>28</sup>Other RATGs affect the radiative balance of the atmosphere, but their main influence is not through absorption of energy reradiated from the Earth's surface; these include aerosol particulates such as sulfur dioxide (SO<sub>2</sub>), which can reflect insolation and thus may exert a net cooling influence.

<sup>29</sup>For purposes of predicting trace gas concentrations and lifetimes, "sources" includes all anthropogenic, biogenic and other sources of RATGs emitted into the atmosphere. When calculating nations' RATG net emissions inventories and the effects of policy actions, the sources of concern are those influenced by human activity.

<sup>30</sup>For purposes of predicting RATG concentrations and lifetimes, "sinks" includes all anthropogenic, biogenic, atmospheric and other activities, processes, and phenomena that remove greenhouse gases from the atmosphere or reduce their atmospheric lifetimes. Examples of sinks include soils and trees, oceanic phytoplankton, ocean mixing, and atmospheric chemical reactions. When calculating nations' RATG net emissions inventories and the effects of policy actions, the sinks of concern are those influenced by human activity.



contribution of increments of each gas to physical effects, such as radiative forcing, used as proxies for global environmental impacts. The comprehensive approach thereby avoids ignoring the important gases that would be omitted from a CO<sub>2</sub>-only approach, and avoids ignoring important sources and sinks that would be omitted from an energy-only approach.

RATGS also emanate from diverse sources and are removed from the atmosphere by diverse sinks (see Table 4). Because the focus of environmental inquiry is the change in atmospheric concentrations of the gases, not source emissions per se, the comprehensive approach encompasses all of these sources and sinks in the concept of "net emissions."

#### B. Policy context

The comprehensive concept is an "approach" or heuristic that offers insight into any discussion of response strategies for potential climate change. It addresses the "how to" question -- how to design any policy (including research, technology development, and other options) that might be adopted to respond to potential climate change. Its principal aim is to improve the framework of research and analysis, and the cost-effectiveness of any choice, by encompassing all the important variables and guiding investments of time and effort to those that are most important. It does not directly address the larger cost-benefit question of "how much" investment of time and effort should be made -- what level of social investment, if any, is warranted by risks of potential climate change. By shedding light on the full costs and benefits of alternative proposals, it does help to answer the "how much" question.

#### C. Multiple applications.

The utility of a comprehensive approach is not limited to the design of emissions limitation policies. Whether the strategy is pursuing scientific research, promoting new technology, evaluating policy proposals, identifying measures warranted on other grounds that also have potential climate benefits, or designing actual emissions limitations policies (whether domestic or international), a comprehensive approach suggests the desirable breadth, emphasis and direction of the strategy. It provides the guide to maximize the environmental benefit of any expenditure of social resources.

As a means of defining the agenda for science and economics research (such as research on the likelihood or impacts of potential climate change, or on the means, costs and benefits of response options), the comprehensive approach ensures that all RATGs, sources and sinks are considered, and that environmental impacts (including radiative forcing and other effects) are



considered. It also suggests the key areas for improved measurement of sources and sinks of RATGs. And it provides a guide to the benefit that will be obtained from improved knowledge of each variable in the human-climate system. A framework convention on climate change could take a comprehensive approach to the cooperative scientific and economic research to which the parties commit, including the development of international monitoring networks, as well as to any national emissions reporting. This suggestion is illustrated in Chapter IV.

As an approach to technology development, a comprehensive approach assists in identifying and comparing the relative importance of technologies and practices affecting potential climate outcomes. For example, if nations are to develop or transfer technology under a climate convention, or to provide financial assistance, a comprehensive approach could be used to assess the impact of each project on potential climate change. How would a new facility, or a new method of crop cultivation, affect net RATG emissions? How can ozone-depleting substances be replaced without generating other RATGs? The comprehensive approach provides the tools to answer such questions.

As a means of evaluating current policies or proposed policies, a comprehensive approach provides a metric for identifying and assessing the impacts of policy actions in the climate context. It could form the basis for calculating the aggregate impact of various measures on a nation's net RATG emissions. What would be the climate impact of a new energy tax, revised forestry policies, or a change in agricultural subsidies? Using a comprehensive approach would provide the basis for the proper consideration of any policy options.

As an approach to possible emissions limitation rules or obligations (whether domestic or international), a comprehensive approach provides an environmentally coherent and least-cost design for limitations policy. It provides the proper signals to guide responses to maximize environmental benefit. It also avoids the dangers of a piecemeal approach, focused on one gas (e.g. CO<sub>2</sub>) or one sector (e.g. energy), which would omit salient RATGs, sources and sinks and hence could induce unintended shifts of economic activities from the narrowly regulated aspect to unregulated modes that effectively offset or even increase emissions of RATGs. This danger is evident from experience in more traditional contexts, where, for example, focusing on air emissions alone has led to shifts of pollutants from air to toxic solid sludge discharges. In the climate context, for example, focusing on CO<sub>2</sub> alone could induce fuel-switching from high-CO<sub>2</sub> coal to lower-CO<sub>2</sub> natural gas, meanwhile leading to increased emissions of CH<sub>4</sub> from natural gas facility leaks.



The comprehensive approach cures these environmental defects of a piecemeal approach. It also allows the flexibility to choose the least-cost mix of policy options yielding the desired overall RATG limitation. And, by addressing "net emissions," it encourages sink enhancement such as through afforestation or safeguards against pollution of oceanic phytoplankton. A comprehensive approach could be applied to a variety of emissions limitation measures, including emissions taxes and emissions trading, and including both domestic and international measures. If applied internationally, it has the additional benefit of reserving to each nation the flexibility and autonomy to decide its mix of domestic policies regarding the array of gases, sources and sinks that that nation determines would best accomplish policy goals in light of that nation's unique social, economic, cultural and institutional circumstances.

The comprehensive approach would also employ performance-based incentives rather than the "command-and-control" design standards that have historically been used in environmental policy, requiring those who emit a substance to apply specific technological controls such as "best available control technology." That approach is insensitive to the variation in costs and options faced by diverse emitters; environmental protection could be achieved at less cost if limitations were obtained using the least-cost option in each place. It discourages innovation in control technologies, and efficient use of resources, because the mandated "best" technology is "locked in," with no reward for innovations or reduced consumption of resources. An incentive-based approach would encourage diverse, innovative, cost-effective responses.

D. Experience with the Comprehensive Approach.

1. Stratospheric ozone depletion: the Montreal Protocol. A recent example of a "comprehensive" approach adopted by the international community to address atmospheric environmental policy is the method employed in the Montreal Protocol on Substances that Deplete the Ozone Layer. Indeed, the description above of a comprehensive approach for trace gases bears resemblance to the approach taken in the Montreal Protocol for ozone depleting substances. Parties to the Montreal Protocol are obligated to limit and then reduce their production (and their imports, exports and consumption) of two Groups of substances listed in Annex A.<sup>31</sup> Each substance in Annex A is assigned an "Ozone Depleting Potential" value, calculated to

---

<sup>31</sup>Annex A may be amended in the future to list additional substances that deplete stratospheric ozone.



represent the average cumulative contribution of an additional increment of the substance to ozone depletion. Rather than requiring each nation to achieve specific percentage reductions in each ozone depleting substance, the Protocol requires an overall percentage reduction in the total production of each of the two Groups. Under Article 3, "production" of each Group to be restricted is calculated by multiplying annual production of each substance by its Ozone Depleting Potential, and then adding together the resulting figures.<sup>32</sup> Consumption, imports and exports are limited according to the same approach.

The comprehensive approach employed in the Montreal Protocol is likely to prove advantageous in several respects. First, environmental quality -- in this case, protection of the stratospheric ozone layer -- will be furthered. Each nation will meet its obligation to restrict total production from each Group of substances. If the Montreal Protocol had restricted production of only one substance, economic activity could have adjusted to reduce output of that substance while increasing the output of other ozone depleting substances. In contrast, the approach taken in the Montreal Protocol improves the chances that the most important ozone depleting substances will be restricted, and that activities will not shift to producing other substances that pose as large a threat to the ozone layer.

Second, the comprehensive approach preserves flexibility for nations to design their own best means of compliance. In a piecemeal approach, specific limitations would be required for each substance. Each nation would find some of those limitations extremely costly, but others so inexpensive that further reductions (though not required) would not have been burdensome. Under the Montreal Protocol, however, these inefficiencies are, in principle, largely avoided by permitting each nation to choose within each Group which substances to restrict, so long as the overall weighted production limits are met. Different nations can choose different mixes that take account of the varying Ozone Depleting Potential of each substance and of the varying socioeconomic value of each substance to different societies. For example, a nation whose economy depends heavily on one CFC can reduce those emissions more slowly but take extra steps to reduce its use of another CFC, so long as the overall reduction in weighted production fulfills its obligations. Each nation can thus choose the cost-

---

<sup>32</sup>The Montreal Protocol also allows for limited transfer of this calculated level of production among parties, for the purpose of industrial rationalization. See Article 1, paragraph 8, and Article 2, paragraph 5.



minimizing mix of restrictions to achieve its combined limit of the weighted production amounts of each substance.<sup>33</sup>

Similarly, the Montreal Protocol prudently employs performance-based limits. In contrast to an approach imposing "design standards" or other rules requiring use of specific technologies, the performance-based approach used in the Montreal Protocol requires those who emit a substance to limit emissions, and leaves to the emitter the choice of what methods, technological or otherwise, to employ. As compared to design standards, performance-based limits encourage lower-cost responses by emitters, more innovations in control techniques, and more efficient resource uses, to the benefit of society, while achieving the emissions limit desired.

The concept of "net emissions" described above is not pertinent in the context of the Montreal Protocol because significant human-influenced "sinks" do not exist for the CFCs and halons regulated in Annex A.

2. Multimedia policy. Restrictions on emissions that apply narrowly to one kind of source of a pollutant can result in compliance strategies that, while adhering to the law, fail to reduce environmental degradation. Regulations on one environmental "medium," such as air quality, can induce shifts in pollution to another medium, such as land or water disposal. Recognizing the inherent and recurring problems in a single medium approach, the U.S. is now developing and implementing a more comprehensive, integrated strategy to address the "cross-media" difficulties of our initial system of environmental control. It is examining strategies for "pollution prevention" that address the multiple pollutants that may enter the several environmental media, and that attempt to reduce risk by reducing the total generation of pollution rather than focusing only on the "end of the pipe." It is bringing enforcement actions that simultaneously charge violations under several laws, in order to achieve a multimedia solution to an area's environmental problems. For example, the United States recently brought enforcement actions against several facilities in Northwest Indiana, along the Grand Calumet River, charging violations of the Clean Air Act, the Clean Water Act, the Resource Conservation and Recovery Act (the law governing hazardous waste management), and the Safe Drinking Water Act. By bringing simultaneous

---

<sup>33</sup>The United States, for example, is implementing its obligations under the Montreal Protocol through domestic use of a "comprehensive" approach: U.S. industry must limit its total production, weighted by the Ozone Depleting Potential index. This permits industry to devise the best mix of reductions in regulated substances, encouraging least-cost, innovative responses.



actions against several neighboring facilities and for multimedia discharges under several statutes, the United States is seeking to ensure that the pollutants addressed by one statute are not simply converted into a different form of pollution, and that pollution control at one facility is not offset by increases at another; the goal is to promote the overall environmental quality of the area by dealing with all environmental impacts in a comprehensive fashion.

3. "Bubbles." The use of "bubbles" for air quality protection is a program that bears similarity to the "comprehensive" approach, and it is a program with which the United States has extensive, positive experience. Under the Clean Air Act, each region of the United States must attain ambient air quality standards. Existing, modified, and new sources of emissions are all regulated to achieve the ambient standards; depending on the type of source and whether the area is "in attainment" or not, sources must employ a range of emissions controls. As part of its efforts to implement the ambient air quality requirements and the emissions control requirements, the U.S. Environmental Protection Agency (EPA) designed the "bubble" program. The word "bubble" is used because the design suggests an imaginary bubble covering a plant with multiple emissions sources. Under the "bubble" program and related rules, in attainment areas, the EPA allows existing industrial and utility plants with emissions emanating from multiple sites to reallocate emissions among the sites within the plant or set of plants, so long as total emissions do not increase. Thus, if a plant has several smokestacks, it can rearrange the emissions released from each smokestack so long as the total emissions from all its smokestacks does not increase. States that are delegated authority to implement the Clean Air Act's requirements have also designed "bubble" programs that they allow industrial emitters to adopt.

The "bubble" is a good example of a comprehensive approach to environmental protection that has been in place for several years (since 1979) and that has proved successful. The fundamental principle of the bubble, like that of the comprehensive approach described here for trace gases, is the same: actors should retain the flexibility to rearrange their emissions so long as their total quantity of emissions achieves the aggregate goal.<sup>34</sup>

---

<sup>34</sup>Because the Clean Air Act regulates individual pollutants, each "bubble" is applied to emissions of a single pollutant, and in that respect the "bubbles" differ from the comprehensive approach suggested for application to the multiple array of greenhouse gases. But the bubble approach derives from the same policy rationale that supports the comprehensive approach:  
(continued...)



United States experience with the "bubble" has been extensive and promising. There were 132 approved bubble reallocations in the U.S. between 1979 and 1985. The bubble program has resulted in significant cost savings to society: over these 132 bubble reallocations, savings amounted to over \$430 million, for an average of over \$3 million per use of the bubble program. And these cost savings were obtained even with the potentially expensive requirement that emitters must receive approval for the bubble reallocation from the state and, if the state has not been delegated authority to implement the program, from the regional and national EPA as well.

Moreover, the significant savings under the bubble program have been achieved without any increase in total emissions. In fact, some early evidence indicates that the bubble program has induced net reductions in total emissions.

4. Administration proposal to limit acid precipitation. The Administration proposed, but Congress did not enact, a provision for multipollutant trades as part of legislation to reduce emissions of air pollutants that contribute to acid precipitation. Because acid precipitation is believed to be the result of both SOx and NOx emissions, the Administration proposal regulated both substances and allowed trading between the two. Emitters would have been required to reduce SOx and NOx emissions, but each emitter could have varied its own mix of SOx and NOx reductions, so long as the overall target was attained. The gases were weighted in the proposal so that an extra pound of emissions of SOx above the limit must be matched by more than a pound of reduction in NOx emissions.

5. Canadian NOx-VOCs Management Plan. As part of its recent "Green Plan," the Canadian government has proposed a program to reduce urban smog by limiting emissions of NOx and VOCs. Canada proposes to allow trading between sources and between NOx and VOCs emissions, using a ratio of the gases' impacts on smog production to calibrate the trades, and requiring that aggregate emissions do not exceed government-issued allowances.<sup>35</sup>

6. Agricultural toxics. Recognizing that "it is not just one pesticide that is the source of ... contamination," one commentator has suggested using a comprehensive approach to regulation of the numerous pesticides that are applied to

---

<sup>34</sup>(...continued)  
promoting least-cost approaches to effective environmental protection.

<sup>35</sup> Canada's Green Plan, 1990, pp. 53-55.



farmers' fields. Using an index to relate the comparative impacts of the different chemicals on the environment, the approach would leave to farmers the choice of which chemicals to apply -- so long as the aggregate index-weighted set of chemicals did not exceed the regulated limit. This approach would allow diverse farmers the flexibility to employ different pesticides in different circumstances, while protecting environmental quality by reducing overall contamination effectively. Without such a comprehensive approach, an inflexible requirement of identical reductions by all would deny farmers in different settings, or growing different crops, the opportunity to vary their mix of protective substances; and limits on one pesticide might induce increased use of another, more harmful substance.<sup>36</sup>

---

<sup>36</sup> See Susan Capalbo and Tim Phipps, "Designing in Environmental Quality: Possibilities in U.S. Agriculture," Conference paper presented at American Enterprise Institute, Washington D.C., June 11-12, 1990, pp. 23-24.



## Chapter IV: A Comprehensive Approach to Research and Monitoring

### A. Measuring and Monitoring Atmospheric Concentrations

Any environmental impacts resulting from RATGs would be associated with changes in the actual concentrations of RATGs in the atmosphere, not with emissions per se. The comprehensive approach ensures that data are gathered on atmospheric concentrations of all relevant trace gases. Over the last decade much work along these lines has already been undertaken or accelerated, including (i) direct measurement through ground station, aerial, and satellite observation of atmospheric (tropospheric and stratospheric) concentrations of several trace gases (chiefly CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, O<sub>3</sub>, and CFCs), and (ii) sample records of past climate change found in ice cores, tree rings, and other sites. Measuring and monitoring past, current and future concentrations, temporal and spatial (e.g. vertical) distributions, chemistry, removal, and other dynamics of trace gases will remain an essential function under a comprehensive approach.

Clearly, exclusive attention to CO<sub>2</sub> concentrations, disregarding other RATG concentrations, would not make scientific sense. No professional atmospheric scientist would limit his or her attention to CO<sub>2</sub> alone, for even at their current small concentrations, the effect of the other RATGs on additional (human-induced) radiative forcing are believed to be equal in magnitude to the effects of CO<sub>2</sub>. A comprehensive approach to research and monitoring of atmospheric concentrations, addressing all the RATGs, is clearly warranted. The framework convention should include steps to fill the gaps in our understanding of RATG concentrations, atmospheric processes and dynamics. For example, the convention could:

- o Establish or enhance a global concentration monitoring network for the relevant trace gases. Ensure appropriate geographic coverage to measure gradients and distributions. Develop techniques, methodologies and standards for monitoring, and disseminate this information. Nations would agree to undertake monitoring and share methods and data. The network would build on the many existing systems, such as the WMO Global Atmosphere Watch, rather than create new institutions.
- o Organize data collection centers and structures to receive, code, interpret and report on data collected by the network. Charge the IPCC to coordinate and assess this work.



B. Measuring and Monitoring Net Emissions.

Assessment of current and future net emissions is critical to the task of predicting the contribution of net emissions to atmospheric concentrations and hence to forecasting potential climate change, regardless of whether any emissions limitations are ever adopted.

The comprehensive approach emphasizes attention to all RATGs, sources and sinks. Baseline data on all of these are not always currently available. In addition, much of the data that are available derives from estimates using data on inputs (e.g. fuel quantities) and knowledge of or assumptions about input-output ratios associated with technologies or practices.

Better measurement, forecasting and actual monitoring of net RATG emissions is suggested by, and needed to support, the comprehensive approach. First, such data are needed to establish current baseline net emissions of RATGs, in order to validate current model estimates and resolve uncertainties in the calculations of national and sectoral net emissions. These data will serve to improve estimates of current net emissions, for aggregate and national or sectoral predictions.

Second, these data will be essential to resolving uncertainties in the calculation of comparative gas indices, which depend on estimates of the typical residence times of gas molecules, and thus in turn on information about source-sink balances.

Third, these data will be critical to projecting future net emissions. Predictions of future net emissions trends are a key input into global climate models used to predict atmospheric warming. A piecemeal approach, focusing on CO<sub>2</sub>, could seriously undermine the accuracy of estimates of the real rate and extent of future climate change. A comprehensive approach to net emissions of all RATGs, however, would ensure more accurate and reliable forecasts of future net emissions, and hence of future concentrations.

The measurement of net emissions faces many obstacles and uncertainties, and the framework convention could address these data gaps. Many current studies confine themselves to CO<sub>2</sub> and energy policy alone simply for the reason that, in the words of one analyst, "[t]his focus suggests itself because the necessary quantitative data for a least-cost analysis are far more developed in the case of energy than for other major sources



of greenhouse gases."<sup>37</sup> Unless research is carried out along a comprehensive approach, a narrow and incomplete knowledge base will yield surprises for policy makers, and incomplete and flawed piecemeal policy responses.

In order to improve net emissions monitoring, the Convention should set goals and priorities for research and monitoring following a comprehensive approach. The IPCC or another appropriate body could be tasked to coordinate and assess this work. The convention could advance efforts along the following lines:

- o Organize efforts to harmonize current emissions monitoring methodologies, techniques and systems.

For example, the convention could assemble multinational programs to compare and harmonize the methods used to monitor CH<sub>4</sub> emissions from fossil fuel mines and transmission systems, from livestock, or from rice fields; N<sub>2</sub>O emissions from soil biota under different agricultural practices; and so forth.

To take a recent example: there is some controversy over the proper way to monitor emissions from forestry. At the macro level, there is debate over the techniques for interpreting satellite data in estimating forest cover. At the micro level, there are differences of view over the effectiveness of different tree types, tree ages, and forestry practices (through their effects on trees, soil biota, and moisture) at fixing atmospheric carbon.

The convention could address these topics and set up workshops, expert panels, and research programs to encourage harmonization.

- o Identify and calculate accurate proxies or surrogates to estimate net emissions factors from hard-to-measure activities, such as diffuse sources and sinks in agriculture and forestry. Even today, energy CO<sub>2</sub> emissions are not measured directly by smokestack monitoring devices, but are calculated from data on the carbon content of fuels and the efficiency of the combustion process. Similarly, CH<sub>4</sub> emissions factors for livestock could be tested under diverse conditions and diets, and calculated by applying the emissions factor to the number of cattle (perhaps counted by satellite sampling and ground observation).
- o Sponsor workshops or research programs on atmospheric chemical reactions of relevant trace gases. For example,

---

<sup>37</sup> F. Krause, et al., Energy Policy in the Greenhouse, (IPSEP / European Environmental Bureau / Dutch Ministry of Housing, Physical Planning and Environment, September 1989), Volume One, p. I.1-3.



host a Workshop on Methane Interactions, or a Workshop on HCFC Interactions. The output from the Workshops would help describe how concentrations change (through better knowledge of residence times and dynamics), what gases are indirectly affected or produced by molecules of the subject gas, and hence feed into projections of total warming, calculation of the GWP Index, and consideration of non-warming impacts. Interactions with hydroxyl (OH) radicals in the lower atmosphere are of special interest and in need of study; OH interactions affect (or are affected by) numerous RATGs, including CH<sub>4</sub>, NO<sub>x</sub>, CO, O<sub>3</sub>, and VOCs, yet information is needed about trends in the ambient abundance of OH, specific reaction dynamics, and synergistic effects when multiple RATGs are present.

- o Organize a thorough study of the carbon cycle (atmosphere-ocean-terrestrial sinks). This could build, for example, on the U.S. CEES effort to understand all carbon processes. This work would generate critical information about, among other important topics, CO<sub>2</sub> residence time. CO<sub>2</sub> residence time is uncertain because each carbon atom cycles in and out of the ocean over 5-10 year periods, but is not fully removed from the cycle for hundreds of years or more. Better understanding of the carbon cycle would help specify the radiative forcing index values relative to CO<sub>2</sub>.
- o Create micro-monitoring field programs, to match the concentration monitoring programs described above by measuring actual emissions and uptake from surface activities. For example, better understanding of the biological, chemical, and physical processes involved in the emissions and deposition of N<sub>2</sub>O, CH<sub>4</sub>, and NO<sub>x</sub> is needed. An "Agricultural Methane Emissions Monitoring Program," for example, could provide technical assistance, operate a network of experimental monitoring stations (with host nation permission), operate pilot test monitoring stations to gather data on typical agricultural practices where on-site monitoring is impractical or not permitted, etc. A "Soil Net Emissions Project" could be similarly designed. Monitoring could be organized on topical/sectoral, regional or national emissions bases. The effort would make sure to include coverage of both industrialized and developing country emissions. Clinical and field studies of the key processes involved would also be undertaken. These programs could also develop a data set of emissions/uptake factors for current and potential technologies and practices, covering all relevant gases, sources and sinks, to be used as proxies or surrogates in estimating difficult-to measure (diffuse or non-point) sources and sinks (see bullet 2 above).



- o Develop national inventories. Efforts are already underway to assemble inventories of net emissions of RATGs for many nations, including OECD and U.S. EPA's analysis of CO<sub>2</sub>, CH<sub>4</sub>, CFCs, HCFCs, N<sub>2</sub>O, CO, NO<sub>x</sub>, and NMHCs for the US and other nations. The convention could build outward from these projects to calculate baseline net emissions inventories for all nations. It could invite all nations to regional workshops, and feed the data into centers where these data can be used in emissions forecasting efforts.
- o Develop comprehensive economic models. To forecast future emissions and the effects of policy proposals, new and expanded economic models are needed that cover multiple trace gases, multiple sectors, sinks as well as sources, better detail on developing countries, international trade effects, and so forth. An economics research program could pursue this effort.
- o Organize a program to develop monitoring technology, including remote sensing (satellite observation using lasers, etc.), aerial reconnaissance, on-site instruments, flux measurement techniques, etc. For example, it could create a Tropospheric Ozone Monitoring Technology Clearinghouse. It could encourage development of devices that can be operated in the field at modest skill levels. The program could award recognition, funding, and/or possible forms of international intellectual property rights to scientists, engineers, and others who invent useful devices.

The convention could also address, or task the IPCC to assess, options for institutional arrangements to improve monitoring. These options include arrangements for monitoring and reporting and their relation to sovereignty concerns, e.g. voluntary or mandatory national reporting; remote sensing; atmospheric observations; international oversight bodies; permission for on-site field studies; incentives and institutional designs to encourage development and application of accurate monitoring & reporting, for example by assuring credit for net RATG limitation actions upon a showing by the emitter of successful monitoring practices; international expert panels; international research centers; cooperative monitoring projects.

These options are meant to illustrate the range of research and monitoring topics embraced and spurred by a comprehensive approach. Certainly other research efforts, such as into the role of clouds and oceans, would be needed to develop a complete understanding of the climate system. Yet without attention to a comprehensive approach, even a full understanding of the ocean-atmosphere system would lack crucial knowledge of the human-influenced inputs to potential climate change.



## Chapter V: Environmental Advantages of a Comprehensive Approach

### A. The Pitfalls of Piecemeal Approaches

A comprehensive approach to environmental policy, and to issues of climate change in particular, is highly desirable because its alternative -- a piecemeal approach that focuses on one gas and sector -- is environmentally flawed. If the goal is sound environmental protection, a piecemeal approach is unlikely to succeed and could backfire.

Piecemeal policies are typically beset by a notorious drawback: "shifts" or "displacements" of pollution as activities move away from the regulated area to unregulated but still deleterious forms. Piecemeal policies place a regulatory or financial burden on certain targeted activities, such as emissions sources of a certain pollutant. Rational, law-abiding businesses and individuals react to that burden by finding other legal ways of running their operations -- new emissions controls, new fuels, new product materials, new process designs, new products, new plant locations, new emissions outlets -- that avoid the burden. But the new operations typically produce other types of "residuals" -- emissions or wastes that injure the environment -- thus undermining, counteracting, or even reversing the protective effect of the piecemeal policy. By squeezing on only one end of the socioeconomic balloon, piecemeal policies simply make the balloon bulge out at another end.

This problem is especially acute in the climate context, where the several trace gases are emitted by virtually every sector and type of human activity, from energy to industry to agriculture, on every part of the planet. The social and economic activities that produce these trace gases, from fuel combustion to traditional agriculture, are intricately interrelated and widespread. Policies that restrict emissions of one trace gas from one source, such CO<sub>2</sub> from energy production, are bound to induce shifts to activities that yield emissions of other gases, or in other sectors, not targeted by the piecemeal policy. These shifts would seriously impair the environmental effectiveness of the piecemeal policy, and could even mean net increases in contributions to radiative forcing.

#### 1. Past Experience with Piecemeal Policies

Historically, piecemeal policies have often proved environmentally ineffective or even counterproductive. The history of environmental policy has been piecemeal; command and control efforts have in almost every country been aimed separately at the three main environmental "media": air, water, and land. This has often led to "cross-media shifts" in



residuals, moving pollution around without reducing it.<sup>38</sup> Past experience in the United States, for example, demonstrates the reality and the likelihood of such shifts. The major U.S. environmental laws, such as the Clean Air Act, the Clean Water Act, and the hazardous waste statutes, were each written to address one environmental medium. Breaking pollution control down into these piecemeal categories may initially seem logical, but we have learned through frustrating experience that shifts from one environmental medium to another have thwarted attempts to reduce pollution.<sup>39</sup> One commentator has aptly observed: "In attempting to help Eastern Europe, the Soviet Union, and the Third World with air pollution problems, western industrial countries should not simply transfer wholesale the [end-of-pipe] pollution control strategies that have not been entirely successful at home. An ill-conceived approach such as this could do more harm than good. ... A comprehensive approach will be necessary that focuses on pollution prevention rather than pollution control."<sup>40</sup>

For example, stringent regulations on water pollution have induced industry to convert liquid pollutants into sludge, in turn creating toxic waste disposal problems. Similarly, to reduce air pollution, standards were written to require installation of "scrubber" technology to remove sulphur dioxide (SO<sub>2</sub>) emissions from electric utility smokestacks. Yet these rules have resulted in increased generation of solid wastes.<sup>41</sup> Another unanticipated dysfunction of the scrubber requirement is that while it removes SO<sub>2</sub>, attaching the scrubber impairs the operating efficiency of the utility boiler, so that more fuel is needed to produce the same amount of energy. In consequence, SO<sub>2</sub>

---

<sup>38</sup> See U.S. EPA, Science Advisory Board, "Reducing Risk: Setting Priorities and Strategies for Environmental Protection," SAB-EC-90-021 (September 1990), Recommendation 7, p. 22, and Strategic Options Report, section 4.3.

<sup>39</sup> See Office of Technology Assessment, From Pollution to Prevention 1987; Daniel J. Dudek, "Lessons from U.S. Experiments in Environmental Reform," Environmental Defense Fund, presented at the international workshop on Institutional Design for Environmental Protection in Poland, September 17-20, 1990, at 9.

<sup>40</sup> Hilary F. French, "Clearing the Air," in Worldwatch Institute, State of the World 1990 at 118.

<sup>41</sup> See Dudek, "Lessons," supra note 1; Hilary F. French, "Clearing the Air," in Worldwatch Institute, State of the World 1990 at 111.



emissions were reduced but other pollutants generated by fuel combustion -- such as CO<sub>2</sub> -- were increased.<sup>42</sup>

Restrictions on emissions that apply narrowly to one kind of source of a pollutant can also result in compliance strategies that, while adhering to the law, fail to reduce environmental degradation. For example, laws regulating smokestack air pollution were written to require that the ambient air quality in the locality of the smokestack not fall below certain levels. One industry response to this approach was to build taller smokestacks, so that the pollutant plumes were fed into higher wind currents and were dispersed more rapidly from the local area. Although pollutants were removed from local areas, they often continued to degrade the environment farther downwind. The result was that, although no law was violated, overall pollution was reduced much less than the law had contemplated. Although spreading these pollutants downwind did dilute their concentrations and thus reduce threats to human and ecological health, the strategy of building tall smokestacks meant that the environmental benefits were much less than hoped. And populations downwind received unexpected pollutant loadings. Later, the laws were amended to try to prevent such outcomes.

Recognizing the inherent and recurring problems in a piecemeal approach to pollution, the U.S. is now developing and implementing a more comprehensive, integrated strategy to address the "cross-media" and "cross-source" difficulties of our system of environmental control. It is examining strategies for "pollution prevention" that address the multiple pollutants that may enter the several environmental media, and attempt to reduce risk by reducing the total generation of pollution rather than focussing on the "end of the pipe."<sup>43</sup> It is bringing enforcement actions that simultaneously charge violations under several laws, in order to achieve a multimedia solution to an area's environmental problems. For example, the United States recently brought enforcement actions against several facilities in Northwest Indiana, along the Grand Calumet River, charging violations of the Clean Air Act, the Clean Water Act, the Resource Conservation and Recovery Act (the law governing hazardous waste management), and the Safe Drinking Water Act.

---

<sup>42</sup> See Daniel J. Dudek, Alice M. LeBlanc, and Peter Miller, "SO<sub>2</sub> and CO<sub>2</sub>: Consistent Policymaking in a Greenhouse," Environmental Defense Fund, New York, January 1990.

<sup>43</sup> See U.S. EPA, Science Advisory Board, "Reducing Risk: Setting Priorities and Strategies for Environmental Protection," SAB-EC-90-021 (September 1990), Recommendation 7, p. 22, and Strategic Options Report, section 4.3.



By designing policy and enforcement to address simultaneously several pollutants at several facilities under several statutes, the United States is seeking to ensure that the pollutants targeted by one statute are not simply converted into a different form of pollution, and that pollution control at one facility is not offset by increases at another. The goal is to reduce overall pollutant emissions as pollution is prevented, and to enhance the overall environmental quality of the nation. Dealing with all environmental impacts in a comprehensive fashion will substantially improve the ability to reduce deleterious pollution while heading off compliance strategies that merely shift pollution around.

Along these lines, one of the best examples of a global environmental policy -- the Montreal Protocol -- was itself designed in a comprehensive way that reduced the potential for cross-pollutant shifts. If the Protocol had restricted production of only one substance, such as the most prevalent CFC, economic activity might have adjusted to reduce output of that substance while increasing the output of other ozone depleting substances. In contrast, the multi-substance approach taken in the Montreal Protocol, using the Ozone Depleting Potential (ODP) index to weight the substances, greatly improves the chances that the most important ozone depleting substances will be restricted, and ensures that activities will not shift to producing other substances that pose as large a threat to the ozone layer.<sup>44</sup>

## 2. Shifts in the Climate Context

Unwanted shifts of emissions to unregulated activities are likely to plague piecemeal policies in the climate context as well. Rational actors reacting to piecemeal policies are likely to pursue unregulated means to their goals, potentially inadvertently continuing to contribute to radiative forcing. The dominant tenor of current policy discussion on climate has

---

<sup>44</sup> At the same time, the ODP values do not account for the global warming potential of the CFCs or their substitutes. See Donald A. Fisher, et al., "Model Calculations of the Relative Effects of CFCs and their Replacements on Stratospheric Ozone," 344 Nature 508 (April 5, 1990); and Fisher, et al., "Model Calculations of the Relative Effects of CFCs and Their Replacements on Global Warming," 344 Nature 523 (April 5, 1990). In this sense the Montreal Protocol is piecemeal, addressed only at the stratospheric ozone depletion problem, and in compliance with the Protocol economic activity may shift to CFC-substitutes that have lower ODPs but have significant GWPs. A more comprehensive approach that accounts for all of the CFCs' and CFC-substitutes' atmospheric impacts, including both ozone depletion and climate change, would address this problem.



focused piecemeal on one narrow aspect: CO2 emissions from the energy and transport sectors. Yet that focus, or any other piecemeal focus in the climate context, is likely to yield dysfunctional shifts in emissions. Precisely because the human activities that produce radiatively active trace gases are so widespread, varied, and currently ingrained in both industrialized and developing societies, shifts are especially likely to occur in the climate context.

(a) Fuel switching, CO2 and CH4. A salient example of a plausible cross-gas shift is the case of "fuel switching." Under a piecemeal CO2-only limitations policy, utilities and businesses would likely be encouraged to switch from coal or oil to natural gas, because with current combustion techniques coal burning produces almost twice as much CO2 per BTU as burning natural gas, and oil burning produces about 50% more.<sup>45</sup> Several studies show that imposition of a constraint on CO2 emissions would lead to considerable fuel-switching from coal and oil toward natural gas,<sup>46</sup> because fuel switching is estimated to be one of the most cost-effective means utilities have to reduce their CO2 emissions.<sup>47</sup> Several national plans have proposed

---

<sup>45</sup> See Rodhe, "A Comparison of the Contribution of Various Gases to the Greenhouse Effect," 248 Science, 8 June 1990, p. 1218.

<sup>46</sup> See, e.g., Interagency Task Force, "The Economics of Long-Term Global Climate Change: A Preliminary Assessment," U.S. Department of Energy, OPPA, DOE/PE-0096P, September 1990, pp. 26, 29; Manne & Richels, "CO2 Emission Limits: An Economic Analysis for the USA," paper presented at the Workshop on Energy and Environmental Modeling and Policy Analysis, MIT Center for Energy Policy Research (July-Aug. 1989); U.S. Congressional Budget Office, "Carbon Charges as a Response to Global Warming: the Effects of Taxing Fossil Fuels," August 1990, pp. 27-30, 44; Commission of the European Communities, DG XII, JOULE Program, "CO2 Study: Crash Programme: Cost-Effectiveness Analysis of CO2 Reduction Options, 'Bottoms-Up' Approach," Parts I and II (working draft Oct. 1990).

<sup>47</sup> See Daniel J. Dudek and Alice LeBlanc, "Offsetting New CO2 Emissions: A Rational First Greenhouse Policy Step," 8 Contemporary Policy Issues 29 (July 1990), pp. 38-39, Table 4; Commission of the European Communities, DG XII, JOULE Program, "CO2 Study: Crash Programme: Cost-Effectiveness Analysis of CO2 Reduction Options, 'Bottoms-Up' Approach," Parts I and II (working draft Oct. 1990).



switching to natural gas as key parts of their domestic policies to limit CO2 emissions.<sup>48</sup>

But use of natural gas means methane (CH<sub>4</sub>) leakage from natural gas mining and transmission systems (pipelines and local distribution networks). Because CH<sub>4</sub> is itself the product being transported and sold, where energy markets are competitive there is a market incentive to capture fugitive CH<sub>4</sub> emissions. But where markets are less competitive or where the cost of capture exceeds the revenue to be gained from the leaking CH<sub>4</sub>, leaks go uncorrected. Today CH<sub>4</sub> leaks from natural gas transmission average about 2-4% worldwide.<sup>49</sup> For example, the average is probably about 1% in the U.S.,<sup>50</sup> it is 3% in Australia,<sup>51</sup> and is probably in the range of 5-10% in the Soviet Union and Eastern Europe.<sup>52</sup>

Switching from coal to natural gas would be encouraged by a CO<sub>2</sub>-only policy, but might not reduce, or could even increase, contributions to radiative forcing. One recent study<sup>53</sup> estimates that a 6% rate of CH<sub>4</sub> leakage from natural gas

---

<sup>48</sup> See, e.g., "Climate Change Policy in the Netherlands and Supporting Measures," Netherlands Ministry of Housing, Physical Planning and the Environment, D.G. for Environment, November 1990, § 3.2.1., p. 6; "Protecting the Earth's Atmosphere," Report of the Federal Cabinet Study Commission, Bonn, Germany, November 7, 1990.

<sup>49</sup> See IPCC Response Strategies Working Group, "Methane Emissions and Opportunities for Control," coordinated by Japan Environment Agency and U.S. EPA (September 1990), p. 34.

<sup>50</sup> Communication from John Hoffman, U.S. EPA, Office of Air & Radiation.

<sup>51</sup> See Jim Falk & Andrew Brownlow, The Greenhouse Challenge (Penguin Books Australia, 1989), p. 270, citing Walker, I.J., and Lydall, K.D., "The Potential for Reduced CO<sub>2</sub> Emissions through Increased Energy Efficiency and the Use of Renewable Energy Technologies in Australia," Commonwealth Dept. of Primary Industries and Energy, Canberra (1989), p. 13.

<sup>52</sup> Communication to U.S. EPA, Office of Air & Radiation, Office of Atmospheric & Indoor Air Programs, Global Change Division, from OEKO-Institute Bro Darmstadt, FRG, based on study by A.A. Arbatov, Deputy Chairman, USSR Academy of Sciences Commission for the Study of Production Forces and Natural Resources.

<sup>53</sup> Rodhe, "A Comparison of the Contribution of Various Gases to the Greenhouse Effect," 248 Science, 8 June 1990, p. 1217.



transport would completely negate all of the CO<sub>2</sub>-related radiative forcing avoided by switching from coal to natural gas (and a 4% leakage rate would completely negate all of the CO<sub>2</sub>-related radiative forcing avoided by switching from oil to natural gas).<sup>54</sup> Thus, at today's world average CH<sub>4</sub> leakage rates, the reduced CO<sub>2</sub>-related radiative forcing achieved by coal-to-gas fuel switching would be offset about 50% by CH<sub>4</sub> leaks. In other words, if implemented through coal-to-gas fuel switching, a policy to reduce CO<sub>2</sub> emissions by, say, 20% would actually achieve only a 10% reduction in CO<sub>2</sub>-equivalent contributions. That would be a major failure of the CO<sub>2</sub> limitations policy. And in the Soviet Union and Eastern Europe, currently major coal consumers with access to large supplies of natural gas, the CO<sub>2</sub>-related reductions from coal-to-gas switching would be offset more than 100% -- that is, net contributions to radiative forcing would actually increase in response to the CO<sub>2</sub>-only emissions policy.

If implemented through oil-to-gas fuel switching, the reduced CO<sub>2</sub>-related radiative forcing induced by the CO<sub>2</sub>-only policy would be offset even more, by about 100% worldwide -- that is, the CO<sub>2</sub>-only policy would have no effect whatsoever on aggregate radiative forcing, with the likelihood of quite significant net increases in radiative forcing when applied in Eastern Europe.

The comprehensive approach, on the other hand, would account for CH<sub>4</sub> emissions and thereby ensure that methane leakage is included in a nation's net trace gas emissions inventory and in the incentives and efforts to limit net emissions. Indeed, in some nations the capture of CH<sub>4</sub> leaks might be a highly cost-effective strategy for limiting contributions to radiative forcing. But a CO<sub>2</sub>-only policy would ignore that option and discourage it, in effect encouraging CH<sub>4</sub> leaks.

(b) Non-energy shifts. Shifts among trace gases are possible in the agriculture and forestry sectors as well. Some proposals to reduce methane emissions from wet rice cultivation involve increased application of nitrogenous fertilizers, which yield nitrous oxide emissions.<sup>55</sup> Certain proposals to reduce methane emissions from livestock also depend on increased use of

---

<sup>54</sup> Rodhe's calculations do not account for CH<sub>4</sub> leaks from coal mining, so these leakage rates would need to be slightly higher to offset all the radiative forcing avoided by reducing coal consumption.

<sup>55</sup> EPA, Policy Options for Stabilizing Global Climate (Draft August 1990), pp. V-157, V-161, V-163.



feed grains grown with nitrogenous fertilizers.<sup>56</sup> Given that the radiative forcing potential of nitrous oxide over a mid-range period (100 years) is over 10 times larger than that of methane,<sup>57</sup> small tradeoffs could be significant enough to offset or outweigh the savings in methane-equivalent emissions. Similar risks are present in the forestry sector, where calls to increase the productivity of trees as CO2 sinks might be pursued by applying nitrogenous fertilizers.

(c) Shifts across sectors. Shifts could occur across sectors as well. If a CO2-only policy induced the substitution of ethanol (made from corn) for carbon-containing petroleum gasoline, CO2 emissions would decline, assuming the corn farm did not displace CO2 sinks. But corn cultivation is one of the most fertilizer-intensive of crops,<sup>58</sup> and nitrous oxide emanating from the application of nitrogen fertilizers to corn fields is roughly 200 times more potent a RATG than CO2.<sup>59</sup> Similarly, a policy aimed at the transport sector alone could encourage the use of electric vehicles (EVs), which themselves emit no CO2. But the full emissions of the EVs depend on what source of energy charges their batteries: if the charging came from coal-fired power plants (whose emissions are not counted in the "transport-only" policy), the net contribution to CO2 emissions and to radiative forcing could actually increase.<sup>60</sup> To take another example, policies to stop deforestation and thereby preserve CO2 sinks could inadvertently increase CO2 emissions, because communities that now burn harvested wood for fuel may turn to coal for their energy.

These shifts may not be inevitable; technologies and practices could perhaps be chosen that take account of all relevant trace gas emissions. But without the system-wide outlook and the incentives provided by a comprehensive approach, the choice of optimal technologies is extremely unlikely. Under

---

<sup>56</sup> EPA, Policy Options for Stabilizing Global Climate (Draft August 1990), p. V-166.

<sup>57</sup> IPCC Scientific Assessment (1990), Table 2.8.

<sup>58</sup> EPA, Policy Options for Stabilizing Global Climate (Draft August 1990), p. V-160.

<sup>59</sup> IPCC Scientific Assessment (1990), Table 2.8.

<sup>60</sup> This observation is buttressed by data in a recent study and a seminar presentation by its authors. See Hadi Dowlatabadi, Alan Krupnick, and Armistead Russell, "Electric Vehicles and the Environment: Consequences for Emissions and Air Quality in Los Angeles," Resources for the Future, Draft 1990.



piecemeal proposals, there is no reason to think that an overall optimal emissions outcome would emerge, and there is every reason to think that narrow efforts will yield narrow results. Piecemeal policies to limit air, water and land pollution have regularly produced inadvertent shifts of emissions. The much more numerous and interrelated socioeconomic systems and practices that generate net emissions of the several trace gases provide a much more complex catacomb of unseen passageways for such shifts to occur. In the climate context perhaps more than in traditional environmental areas, piecemeal policies seem to be a recipe for dysfunction and disappointment.

### 3. Piecemeal coverage of emitters

A different kind of inadvertent shift is the result of policies that address only a subgroup of emitters. If the environmental problem were pollution of a lake, it would make little sense to restrict pollutant discharges from one beach on the lake, but leave sources of pollution around the rest of the lake unregulated; polluting industry on the regulated beach could comply with the law by moving around the lake, or by extending discharge pipes around the lake to emit pollutants in the unregulated zone. Similarly, if one is worried about regional air pollution, it makes little sense to forbid emissions in one local area while leaving neighboring areas unrestricted; industry will move to the unregulated area and continue emitting. These are examples of a general flaw in policies that apply piecemeal to subgroups of sources emitting pollutants that mix in the shared environment: if the scope of policy coverage fails to encompass all the emitters, emissions will shift to the unregulated areas and the environment will not be much improved.

In the climate context, such shifts would be likely to attend restrictions on trace gas emissions applied piecemeal to one nation or group of nations. Because the trace gases relevant to climate change mix globally in the atmosphere and their effects would be global, emissions at any location are equally important to the global ecosystem. Limits on emissions by one subgroup of emitters must be evaluated in terms of their influence on overall global emissions.

Take for example the proposal for only a few nations to restrict their CO<sub>2</sub> emissions, or the view that climate change could be adequately addressed by CO<sub>2</sub> emissions limits imposed solely in the industrialized nations of the OECD. These proposals are inadequate for several reasons. First, any trace gas limits would need to be global because the emissions of the industrialized nations make up a rapidly declining share of global emissions:



### Growth Rates of CO2 Emissions<sup>61</sup>

| <u>Time Period</u> | <u>U.S.</u> | <u>OECD</u> | <u>Non-OECD</u> |
|--------------------|-------------|-------------|-----------------|
| 1966-1976          | 2.40        | 3.51        | 5.22            |
| 1976-1986          | -0.47       | 0.58        | 2.43            |

If the developing nations continue on current trends, absent steps to avoid land use practices and energy production methods that emit substantial amounts of trace gases, by 2030 they will account for roughly half of global CO2 emissions. Even at today's shares, a 20% reduction in current CO2 emissions by the OECD alone would remove only 3% of current global human contributions to radiative forcing. (CO2 from fossil fuels make up 34-37% of global contributions to the enhanced greenhouse effect in the 1980s (with deforestation accounting for 22-26%, CFCs 20%, and other gases 20-21%),<sup>62</sup> so a 20% reduction in global CO2 would be about a 7% reduction in global radiative forcing; and OECD nations now account for 43% of fossil fuel CO2 emissions,<sup>63</sup> so a 20% reduction in their CO2 emissions would reduce global CO2 by about 3%.) OECD-only policies simply could not achieve a global 20% reduction in CO2 emissions -- to say nothing of RATG emissions generally -- without action by the developing nations as well. Without developing country reductions, the OECD would have to eliminate more than 100% of its CO2 emissions to reduce global emissions by 20%.<sup>64</sup>

---

<sup>61</sup> Calculated from Gregg Marland, "Estimates of CO2 Emissions from Fossil Fuel Burning and Cement Manufacturing Based on U.N. Energy Statistics and U.S. Bureau of Mines Cement Manufacturing Data," Oak Ridge National Laboratory, ORNL/CDIAC-25, NDP-030 (1989). If these data included CO2 emissions from land clearing, the growth rates in the Non-OECD would be even higher.

<sup>62</sup> R.A. Houghton, "The Global Effects of Tropical Deforestation," 24 Env't Science & Technology (1990) p. 414.

<sup>63</sup> Interagency Task Force, "The Economics of Long-Term Global Climate Change: A Preliminary Assessment," U.S. Department of Energy, OPPA, DOE/PE-0096P, September 1990, p. 18, Table III.1.

<sup>64</sup> Interagency Task Force, "The Economics of Long-Term Global Climate Change: A Preliminary Assessment," U.S. Department of Energy, OPPA, DOE/PE-0096P, September 1990, pp. 19-21, Tables III.2 & III.3.



Second, the effectiveness of an OECD-only reduction policy would be limited by the possibility of shifts in emissions to other nations where no restrictions apply, offsetting or even increasing in emissions worldwide. As the nations who decided to reduce CO2 emissions (the "signatories" to a limitations agreement) restricted their consumption of fossil fuels, world prices of those fuels would fall. The reduced prices would lead to increased consumption in other nations where limits on CO2 emissions were not in place ("non-signatories"). The increased consumption could partially or even totally offset the reduced CO2 emissions achieved by the signatories.<sup>65</sup> In addition, if the change in the world fuel price led to more consumption by the non-signatories than the initial reduction by the signatories (i.e. if the price elasticity of demand of the non-signatory economies were high), net fossil fuel consumption could actually increase as a result of the signatories' action. And net CO2 emissions would be given additional upward pressure if the amount of CO2 emitted per unit of fuel consumed were higher in the non-signatory economies than in the signatory economies.

Third, over the slightly longer term, restrictions by the subgroup of emitters would be offset as products made with high-emitting technologies were increasingly manufactured in the non-signatory areas and imported back into the signatories, and as high-emitting industries moved out of the signatory states to unregulated locations in the non-signatory states.

Fourth, as described earlier in this Chapter, limits on CO2 alone would not effectively address overall contributions to radiative forcing. A comprehensive approach to all RATGs is warranted.

Comprehensive scope of coverage and wide global participation in any trace gas limitations measures would therefore be essential. As the IPCC noted, "Climate change is a global issue; effective responses would require global cooperation."<sup>66</sup>

---

<sup>65</sup> See Interagency Task Force, "The Economics of Long-Term Global Climate Change: A Preliminary Assessment," U.S. Department of Energy, OPPA, DOE/PE-0096P, September 1990, p. 27; Peter Bohm, "Mitigating Effects on Fuel Prices from Incomplete International Cooperation to Reduce CO2 Emissions," (draft December 1990).

<sup>66</sup> IPCC RSWG Policymakers' Summary p. ii.



## B. Optimal Environmental Signals

A comprehensive approach to research and policy provides optimal environmental signals to guide choices. While a piecemeal approach would ignore and omit important RATGs, sources and sinks, a comprehensive approach would make clear the relative environmental significance of each factor, and encourage decisionmakers to design responses -- whether they be research strategies, technology choices, or emissions limitation incentives -- that generate optimal environmental results.

In order to provide a sound guide to policy choices, a measure of the relative environmental impacts of the gases, an "index" as described in Chapter II above, should be used to set priorities. Rather than taking piecemeal stabs in what might be called the proverbial "radiative darkness," good policy choices demand elucidation of the relative effects of the various emissions. And it must be recognized that some weighting of the gases is unavoidable: a piecemeal policy targeting CO<sub>2</sub> alone effectively weights the other gases at zero.

The comprehensive approach provides the signals that enable the environmental benefit of any response measures to be maximized. Such environmental signals are needed if real environmental benefit is to be achieved. Otherwise, priorities will be set haphazardly, rather than in furtherance of ecological well-being.

Aiming at one RATG alone, for example, would omit other gases with potentially greater adverse impact on the ecological system. Take the case of CO<sub>2</sub>-only policies: CO<sub>2</sub> is, molecule for molecule, the least potent radiative forcing agent of the major anthropogenic trace gases. Because any limitation policies must necessarily address future increments of net emissions, it is the comparative impact of additional amounts of each gas that must be addressed. Meanwhile, CO<sub>2</sub> may provide significant environmental benefits that the other trace gases do not: CO<sub>2</sub> is the grist of photosynthesis, and can improve plants' water use efficiency as well. The other trace gases confer no such benefits, and some pose serious threats beyond radiative forcing; CFCs deplete the stratospheric ozone layer, while other RATGS are toxic. In sum, if one is really interested in promoting global environmental welfare, and if global warming is really a threat warranting preventive action, then policies aimed at restricting CO<sub>2</sub> alone would not be ideal, and could be counterproductive: CO<sub>2</sub> is in a sense the most benign of the RATGs, and for any given level of warming that might occur, one would probably prefer (assuming for the moment equal costs of abatement across gases) to have as much of that given warming due to emissions of low-forcing, plant-



enriching CO<sub>2</sub> as possible, and less due to the other RATGs according to their relative environmental impacts.

Beyond the case of CO<sub>2</sub>-only emissions limitations, the comprehensive approach continues to offer the guidance for optimal decisions to maximize environmental benefits per unit of social resources expended. How is a project manager to choose between two agricultural techniques, one which emits methane and the other nitrous oxide? How is a nation to make the same kind of choice? The comprehensive approach provides the signals to yield optimal environmental outcomes to these choices.

The use of performance-based incentives under a comprehensive approach would also improve the environmental performance of any response measures. Historically, command-and-control regulations have required those who emit a substance to apply specific technological controls, such as "best available control technology." That approach discourages innovation in control technologies, because the mandated "best" technology is "locked in" and innovations are not rewarded. And it discourages improvements in raw materials choices and resource use efficiency that would limit the total amount emitted, because it gives businesses no incentive to conserve fuels or otherwise minimize emissions once the control technology is in place.<sup>67</sup> Hence technology standards dampen the innovation and resource use efficiency that is critical to promoting environmental quality over the longer term. The comprehensive approach, by employing a performance-based incentive that leaves the choice of the means to comply to the individual emitter, encourages least-cost, innovative, and resource-efficient responses.

#### C. Net emissions: enhancing sinks

The comprehensive approach gives sinks the serious attention they deserve. For RATGs, it is net emissions that would be of ecological concern, the result of both emissions from sources and removal by sinks, including trees, grasses, soil biota, oceanic phytoplankton that fix atmospheric carbon, and crops.

By addressing "net emissions," the comprehensive approach would thus give incentives for sink conservation and enhancement. Preserving and properly managing forests and other vegetation, or protecting carbon-fixing phytoplankton from

---

<sup>67</sup> That is why, as described in Chapter IV, mandating scrubbers to remove SO<sub>2</sub> resulted in increased CO<sub>2</sub> emissions. See Daniel J. Dudek, Alice M. LeBlanc, and Peter Miller, "SO<sub>2</sub> and CO<sub>2</sub>: Consistent Policymaking in a Greenhouse," Environmental Defense Fund, New York, January 1990.



anthropogenic injury such as from toxic waste disposal at sea, could help sequester carbon released from surface sources. These sink-enhancement actions could carry with them significant side-benefits in biodiversity, oceanic food webs, reduced soil erosion, and better timber management. At the same time, management of sinks is a complex endeavor, and poorly designed sink enhancement policies could have adverse impacts on sink ecosystems.



## Chapter VI: Economic and Institutional Flexibility

### A. Economic flexibility.

If emissions limits are warranted, the comprehensive approach allows each emitter to use that combination of source and sink controls and other measures that is best suited to its economic and other circumstances, achieving environmental protection at significantly lower cost than a gas-by-gas strategy. This approach maximizes the opportunity for and encourages the adoption of diverse, flexible, innovative, and cost-effective solutions to global climate change.

Some have proposed dictating specific percentage emissions reductions for each RATG, and applying those limits uniformly to every nation. It has been suggested that every nation should reduce CO<sub>2</sub> by 20%, CH<sub>4</sub> by 10%, and so on. Yet mandating specific limits on each gas would be significantly more costly than limits designed according to a comprehensive approach, in which an overall limit would apply to each nation's aggregate contribution of net RATG emissions, weighted by an appropriate index. Both approaches would limit net emissions, but the comprehensive approach would permit each nation to adopt its best, least-cost mix of choices for achieving the overall limit.

#### 1. The prevalence of cost variations.

The costs of RATG abatement are certain to vary considerably across countries and across gases, sources and sinks. The variation of costs across gases, sources and sinks, and nations means that what is a least-cost policy for one nation will almost certainly not be the least-cost policy for another. Under the comprehensive approach, each nation would have the autonomy and flexibility to design its own least-cost mix of policies addressing the various RATGs, sources and sinks. Under a piecemeal or gas-by-gas approach, nations would be bound to adhere to the uniform reduction goals set by the international negotiations; this centralized control of response options would clearly impose extreme costs on certain nations, and would unnecessarily raise overall costs worldwide.

Allowing each nation the flexibility to design its least-cost policy response mix will reduce global costs of any response. Some nations might find it inexpensive to reduce CO<sub>2</sub> emissions significantly, but be unable to reduce CH<sub>4</sub> output (e.g., a nation importing oil and dependent on rice crops, but endowed with untapped solar power opportunities). Those nations would prefer to meet any net emissions limits by reducing CO<sub>2</sub> more rapidly than CH<sub>4</sub>; requiring them to limit each gas by a set amount would prove much more costly (perhaps in terms of lower



economic growth, higher taxes, or reduced rice production) and would leave additional affordable CO<sub>2</sub> reductions unexploited. Other nations might find themselves in the opposite situation, able to afford to limit CH<sub>4</sub> more than CO<sub>2</sub> (e.g., a nation dependent on coal reserves but able to modify the diet of its ruminant animal husbandry).<sup>68</sup>

Including sinks in the calculation of "net emissions" will also offer desirable economic flexibility to nations who are able to comply with trace gas limits more cost-effectively by restoring and promoting sink expansion than by restricting sources. For example, a nation might find it less costly to remove a quantity of trace gases from the atmosphere by planting trees than to prevent emissions of the same quantity of gases from industrial sources. Moreover, sink development could yield additional economic advantages, including reducing soil erosion from agricultural lands; improving timber supply management; enhancing tropical forest biodiversity, which may contribute to useful products such as medicines; and protecting fish harvests by limiting pollution of waters that serve as phytoplankton habitats.

These points are intuitively obvious, because each nation has a different inventory of sources, sinks, and RATG emissions, as shown in Table 5, and hence a different set of RATG emissions reduction options. It makes no sense for a central body to dictate to each nation what that nation's response must be, when the same environmental result could be achieved by that nation at much less cost through a different set of responses.

---

<sup>68</sup> A similar analysis applies to approaches mandating specific changes in sources alone or sinks alone, rather than combining them in a "net emissions" requirement that leaves the domestic policy mix to each nation.



Table 5.A

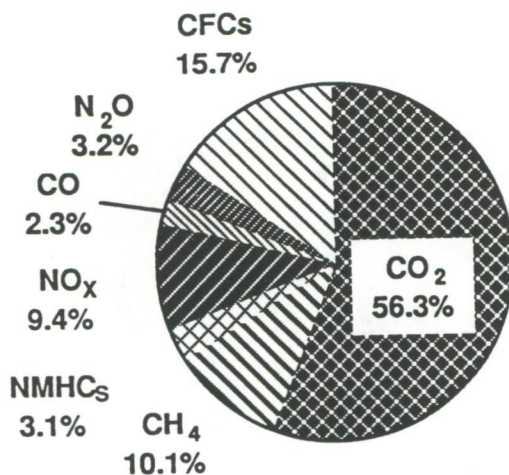
(insert EPA/OECD emissions inventory spreadsheet)



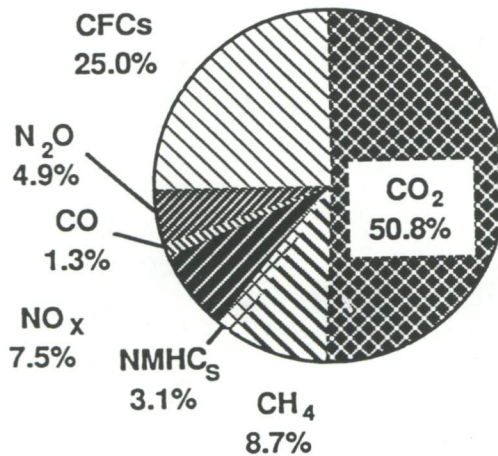
Table 5.8

1987

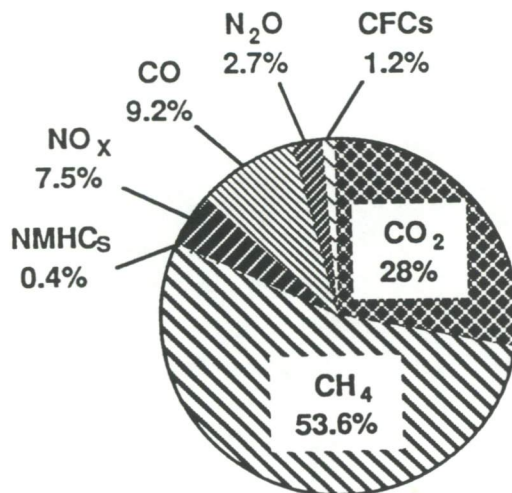
### United States



### United Kingdom



### India



(Source: Dennis Tirpak, "Preliminary Inventories of Greenhouse Gas Emissions By Country," draft August 17, 1990.)

(Using IPCC 100-year GWPs)



The fact that nations' net emissions inventories are different under a comprehensive (all RATG) approach than under a CO2-only approach, it should be noted, does not mean that some nations "win" or "lose" under a comprehensive "ranking" system. "Ranking" is not the point; the point is reducing the marginal cost of RATG abatement. The total size of a nation's emissions does not determine the nation's cost of abatement. For example, Nation A might have small CO2 emissions and large CH4 emissions, so it would "rank" lower on a CO2-only approach. But it would nevertheless benefit from a comprehensive approach, because of the flexibility offered by the comprehensive approach in selecting least-cost response options. Indeed, the cost of abatement in Nation A might well be lower for CH4 than for CO2 -- that is, the marginal cost of reducing its large CH4 emissions might be less than the marginal cost of reducing its CO2 emissions -- in which case it would clearly be better off under a comprehensive approach even though its "ranking" could be higher. The key issue for cost-minimization is the marginal cost of abatement, not total emissions, and a comprehensive approach is very likely to offer reduced marginal cost of abatement to all nations -- every nation "wins."<sup>69</sup>

It is also increasingly clear as an empirical, quantitative matter that the cost of abatement varies significantly across gases and nations. First, recent analyses confirm that costs of abatement vary widely across RATGs. Analysis of additional steps the U.S. might take to limit net RATG emissions in 2000 shows that planting an additional billion trees per year (doubling the billion per year to be planted under the President's Tree Planting Initiative) would cost almost \$100 per ton of carbon-equivalent avoided, while imposing tighter landfill restrictions could reduce VOCs and CH4 at a cost of only about \$11 per ton of carbon-equivalent avoided. These figures are shown in Table 7 below. Nobel Laureate William Nordhaus has estimated that in the U.S., the cost of phasing out CFCs is about \$5 per ton of carbon-equivalent avoided, while options for reducing CO2 emissions begin at about \$10 per ton and quickly rise to hundreds of dollars per ton.<sup>70</sup>

---

<sup>69</sup> A nation whose emissions inventory grew enormously under a comprehensive approach might be somewhat worse off. If Nation B had zero CO2 emissions and truly gigantic CH4 emissions, it might prefer to be governed under a CO2-only approach. But under a CO2-only approach, the significant environmental impact of Nation B's CH4 emissions would be ignored -- not a result that serves the global interest.

<sup>70</sup> See William Nordhaus, "Economic Policy in the Face of Global Warming," Yale University, draft March 9, 1990.



These are simply illustrative examples; these cost figures would not apply in all nations, at all times, or in all regions of the U.S. They make clear, however, that the costs of RATG abatement vary quite widely from gas to gas.

Table 6

**Costs Vary Across RATGs**

| <u>Project</u>                                      | <u>RATG units avoided<br/>(million tons of<br/>carbon-equivalent)</u> | <u>Annual<br/>Costs<br/>(millions)</u> | <u>Cost per<br/>RATG unit<br/>avoided</u> |
|-----------------------------------------------------|-----------------------------------------------------------------------|----------------------------------------|-------------------------------------------|
| Tighter EPA Landfill<br>Restrictions<br>(VOCs, CH4) | 39                                                                    | \$431                                  | \$11                                      |
| Planting 1 Billion<br>More Trees<br>Yearly (CO2)    | 9                                                                     | \$850                                  | \$95                                      |

Source: Alex Cristofaro and Joel Scheraga, "Policy Implications of a Comprehensive Greenhouse Gas Budget," U.S. EPA, OPPE, draft September 1990, Table 7. Calculations use the IPCC 100-year radiative forcing ("GWP") index.

Second, costs vary considerably even among different types of projects to restrict emissions of one gas. Economists at Environmental Defense Fund have estimated the costs of CO2 avoidance through various measures, and have found a wide range of costs per ton avoided, as shown in Table 7. Similarly, the U.S. Forest Service has estimated that the cost of sequestering CO2 in U.S. trees varies from \$5.26 to \$43.33 per ton of carbon.<sup>71</sup>

---

<sup>71</sup> Robert Moulton and Kenneth Richards, "Costs of Sequestering Carbon Through Tree Planting and Forest Management in the United States," U.S. Department of Agriculture, Forest Service, GTR WO-58 (December 1990).



Table 7

**Costs Vary Across Sources and Sinks**

| <u>Option</u>                                              | <u>Cost per Ton CO2 Avoided</u> |
|------------------------------------------------------------|---------------------------------|
| Trees with Conservation Reserve Program (CRP) Contribution | \$3.48-\$5.49                   |
| Trees Without CRP Contribution                             | \$6.64-\$10.67                  |
| Biomass Plantation                                         | \$8.16                          |
| CO2 Scrubbing and Disposal                                 | \$59.41                         |
| Shade Trees                                                | \$1.35-\$6.74                   |
| Conservation                                               | \$5.73                          |
| Fuel switching (oil to gas)                                | \$4.48                          |

(Source: Daniel J. Dudek and Alice LeBlanc, "Offsetting New CO2 Emissions: A Rational First Greenhouse Policy Step," 8 Contemporary Policy Issues 29 (July 1990), Table 4.)

Third, costs can also vary for different levels of investment in a single project, as opportunities to restrict the source or expand the sink become more scarce. That is, there are typically rising marginal costs to expanding RATG avoidance efforts. For example, EPA estimates that sequestering 9 million tons of carbon in trees in the U.S. in the year 2000 would cost about \$545 million, but sequestering an additional 9 million tons of carbon in U.S. trees would cost about \$850 million -- about 75% more -- for a total of \$1.4 billion per 18 million tons sequestered. And repeating that effort, i.e. sequestering another 18 million tons for a total of 36 million tons, would cost another \$2.3 billion -- about 165% more.<sup>72</sup>

These kinds of cost variations, all estimated for the U.S. economy, would undoubtedly occur across nations as well. The great differences in circumstances of different economies -- variations in energy, industrial, transportation, agricultural and forestry systems, in consumption patterns, in capital formation, in labor force characteristics, in land availability, in population density, and so forth -- almost guarantee that the costs of abatement of any one RATG, let alone the costs for abating different RATGs, will be quite different in different nations. Allowing different nations the flexibility to choose different abatement options allows each nation to design its least costly set of measures to achieve global results -- thus reducing net global costs. The comprehensive approach allows

---

<sup>72</sup> R.J. Moulton and K. Andrasko, "Reforestation," 16 EPA Journal 14 (March/April 1990).



such flexibility; a piecemeal approach prevents flexibility across gases, sources and sinks, at higher cost to all.

The socioeconomic costs of policy responses to global climate change could be great. Some studies have indicated that significant emissions reductions would be associated with substantial impairment of economic growth.<sup>73</sup> Some nations and some sectors of society could face especially high costs of limiting emissions of trace gases. For some nations, the costs of unduly inflexible piecemeal emissions limits would mean serious deprivation for residents of economies struggling to develop. It is thus imperative that we choose strategies that will maximize nations' flexibility to select least-cost options and that will provide maximum incentives and opportunities for development of new technologies and other innovative responses that will further reduce costs. A comprehensive approach would contribute substantially to achieving this goal.

## 2. Performance-based incentives

The use of performance-based standards under a comprehensive approach would also improve the economics of response measures. Historically, piecemeal, command-and-control regulations have been implemented by using "design standards" requiring those who emit a substance to apply specific technological controls, such as "best available control technology." That approach has been suggested in the climate context, but it has numerous drawbacks. First, it is insensitive to the costs and benefits of applying each control technology at each site, thus resulting in the same kinds of inefficiencies described above with respect to requiring identical emissions limitations in all nations; environmental protection could be achieved at less cost if limitations were obtained using the least-cost option in each place. Second, it discourages innovation in control technologies, because the mandated "best" technology is "locked in" and innovations are not rewarded. Third, it discourages improvements in raw materials choices and resource use efficiency that would limit the total amount emitted, because requiring application of a specific control technology gives businesses no incentive to conserve fuels or otherwise minimize emissions, once the control technology is in place. These drawbacks make technology standards much less economically efficient than performance-based incentives. The comprehensive approach, by employing a performance-based

---

<sup>73</sup> Several studies are summarized and assessed in Interagency Task Force, "The Economics of Long-Term Global Climate Change: A Preliminary Assessment," U.S. Department of Energy, OPPA, DOE/PE-0096P, September 1990, pp. 23-29.



incentive that leaves the choice of the means to comply to the individual emitter, encourages least-cost, innovative, and resource-efficient responses.

At the same time, performance-based strategies imply good knowledge of performance -- in this case, probably defined by RATG net emissions. Work is needed to improve measurement capabilities, both to predict future RATG concentrations, and to allow performance-based incentives should they be warranted.

B. Social and institutional flexibility.

Taking a comprehensive approach to any emissions limits would reserve to each nation the freedom to employ whatever economic and institutional mechanisms it wishes to use to achieve its objective. Nations would retain the flexibility necessitated by the widely varying legal and cultural systems in different countries. A comprehensive approach would avoid imposing on the autonomy of sovereign states, as would a piecemeal or "design standard" approach that dictates to each nation how it must manage its climate-related policies and sectors.

Under a comprehensive approach, the institutional response of each nation would be its own choice. A free market economy would not be required to employ strict command and control regulations; by the same token, a centrally planned economy would not be required to employ market measures.

In addition to the desire to minimize the costs of achieving any emissions limitation, as described in the previous section, nations may have special needs to continue certain activities intimately tied to their cultures or social systems. A comprehensive approach would be sensitive to these needs, giving nations maximum flexibility to choose their own response options. For example, a mandated CH<sub>4</sub> reduction standard that applied uniformly to all nations would be very intrusive to a nation in which CH<sub>4</sub> derives largely from livestock and the livestock are considered sacred. A piecemeal CH<sub>4</sub> limitation would leave that nation no option but to restrict its herd. Under a comprehensive approach, nations would not be relieved of the obligation to share in any global effort to limit emissions; but by defining the obligation in terms of net RATG emissions and allowing each nation to select its preferred mix of policies that achieve that end, nations would be better shielded from the havoc that could attend an international mandate to disturb deeply rooted social and cultural practices. Instead, nations could choose their steps to limit other RATGs or to address other sources or sinks.



C. "Level playing field."

A piecemeal approach inevitably favors some nations while disproportionately burdening others. For example, a CO<sub>2</sub>-only approach penalizes nations with relatively greater dependence on fossil fuels or fossil fuel revenues, while a CH<sub>4</sub>-only limit could burden nations who rely on rice as a staple. A comprehensive approach provides a more equitable "level playing field" across nations. A comprehensive approach is consequently likely to avoid some of the obstacles to international agreement that would be faced by a piecemeal gas-by-gas approach, such as "blocking" by nations who feared that the initial burden would fall on them.<sup>74</sup> The comprehensive approach would ease such fears.

Moreover, experience shows that once adopted, piecemeal initiatives rarely evolve into a comprehensive strategy. Piecemeal measures tend to create constituencies with vested interests that ensure their perpetuation. For example, the Prevention of Significant Deterioration (PSD) provisions, enacted in the early versions of the U.S. Clean Air Act, limit industrial development in many regions of the nation, often without environmental justification. Other regions oppose efforts to relax or rearrange these limits, for fear that industrial and economic development will shift to the regions that are now subject to PSD controls. The result is that the PSD controls remain in place, in their partial form, constraining balanced economic growth.

Similarly, any global climate agreement that aimed at energy sector CO<sub>2</sub> limitations would benefit certain nations relative to others. The favored nations would resist development of a more comprehensive approach that would treat all nations with an even hand. The result would be incomplete environmental protection, the flaws of a piecemeal policy immovably entrenched, and serious economic distortions. It is accordingly vital to ensure a "level playing field" by adopting a comprehensive approach at the outset. It is much better to get the policy design right at the beginning, and to fill in any gaps through hard work, than to start with a defective policy design and be saddled with it indefinitely.

In a related manner, a comprehensive approach reduces the ability of nations to manipulate the design of international

---

<sup>74</sup> Compare James Sebenius, "Negotiating a Regime to Control Global Warming," in Greenhouse Warming: Negotiating a Global Regime, World Resources Institute (January 1991), pp. 75-78. Sebenius discusses (and conflates) several ways in which issues for negotiation might be combined to avoid "blocking" coalitions.



regulatory measures to advance their own competitive or other economic advantage. A gas-by-gas command and control approach is vulnerable to attempts by nations to "game" the standard-setting agenda in their favor. For example, a nation reliant on non-fossil fuel energy sources, and whose chief rival earns its income from fossil fuel exports, could press for limits on CO2 emissions not for their environmental value but to improve its own competitive standing relative to its rival. Or a wheat-growing nation could press for methane emission limits at the expense of its rice-growing neighbor. Such attempts would hinder international agreement on limits on any particular gas. Such attempts to "game" the design of international regulatory controls are also likely to distort trade and reduce global welfare, as well as impede environmental improvement. By leaving the mix of compliance policies to each nation's discretion so long as the overall limit is not exceeded, a comprehensive approach greatly reduces the potential for such gaming. And a comprehensive approach is likely to promote sober consideration of any emissions limitation proposals by all nations, because few nations could evade all responsibility under a comprehensive approach (as some might under a narrow piecemeal approach).

The comprehensive approach thus reduces the likelihood of "blocking" by those who would be disproportionately burdened by piecemeal measures; and it reduces the ability of rival nations to distort the climate protection effort toward their own parochial ends. At the same time, its broad coverage encourages all nations to examine carefully the costs and benefits of any response measures. These advantages suggest that consensus on any warranted steps would be easier to define, and would better reflect real costs and benefits, under a comprehensive approach. A comprehensive approach would then share burdens more equitably, to everyone's gain.



## Chapter VII: Potential Objections to a Comprehensive Approach, and Replies

A variety of concerns has been raised about the meaning and use of a comprehensive approach. This chapter addresses the objections most often voiced. None of these objections, nor all taken as a whole, warrants rejection of a comprehensive approach. Indeed, several of the objections simply provide the opportunity to clarify the rationale for and workings of a comprehensive approach, and to explain how a comprehensive approach would better serve environmental and economic goals.

### A. "Data and monitoring of sources and sinks are inadequate."

The major objection that has been raised to the comprehensive approach is that the current science is not up to monitoring certain sources and sinks, such as non-point sources of methane and nitrous oxide. The objectors say that we should "do what we can now" and wait until later to design a comprehensive approach. Yet focusing on CO<sub>2</sub> from energy emissions, merely because that is the source most easily measured at present, bespeaks a certain complacency with the current stock of research. Many current studies confine themselves to energy policy alone simply for the reason that, in the words of one of the more candid analysts, "[t]his focus suggests itself because the necessary quantitative data for a least-cost analysis are far more developed in the case of energy than for other major sources of greenhouse gases."<sup>75</sup> And unless comprehensive research is carried out, a narrow and incomplete knowledge base will yield incomplete and flawed piecemeal policy responses.

The more inquisitive comprehensive approach thirsts for research into the key unknowns. Measuring many such emissions will not be easy. But it is not beyond our reach, if we focus current research efforts to support a comprehensive approach. It is particularly in agriculture and forestry that the research toward improved monitoring is most needed. The net emissions data base is perhaps least well-developed for the diffuse, non-point sources and sinks of greenhouse gases that are typical in the agriculture and forestry sectors. For example, recent studies are advancing understanding of carbon sinks: both the

---

<sup>75</sup> F. Krause, et al., Energy Policy in the Greenhouse, (IPSEP / European Environmental Bureau / Dutch Ministry of Housing, Physical Planning and Environment, September 1989), Volume One, p. I.1-3.



total size of the oceanic versus terrestrial sinks,<sup>76</sup> as well as the more localized effectiveness of different types of forestry in sequestering carbon;<sup>77</sup> but the uncertainties surrounding these processes are still significant. As to methane, we are beginning to understand its diverse sources in rice cultivation, livestock, the energy sector, and waste disposal,<sup>78</sup> and its sink in tropospheric chemical reactions; but while we have fairly good data on certain sources such as landfills, the gaps in the data on other sources remain significant. The same holds for nitrous oxide. We will need better estimates of these sources and sinks if we are to forecast future concentrations of the gases, fashion reliable greenhouse gas indices, or calculate baseline and future net emissions for each nation or sector.

The pertinent question, however, is not what is immediately "feasible," but whether the costs of proceeding with a flawed piecemeal policy design are less than the costs of doing the necessary groundwork to develop a comprehensive approach. The groundwork needed to flesh out a workable comprehensive approach is very likely to be less costly than the environmental and economic losses that would attend implementation of a piecemeal approach that is ineffective and inflexible. And as indicated in Section C of Chapter VI, it is better to start with a proper policy design and work hard to fill in any gaps, than to start with a flawed policy design and be stuck with it indefinitely.

And one need not wait for perfection; in the interim, proxy-based estimates of difficult-to-measure emissions could be used. Continuing research, bringing together physical and social scientists with expertise on the critical areas of uncertainty about emissions, is indispensable. International efforts such as the framework convention should build cooperative networks to measure net emissions. International agreements could include incentives for improvements in monitoring, such as offering awards or even emissions credit to those who demonstrate better monitoring techniques.

---

<sup>76</sup> See P. Tans, I. Fung, & T. Takahashi, "Observational Constraints on the Global Atmospheric CO<sub>2</sub> Budget," 247 Science, 23 March 1990, p. 1431.

<sup>77</sup> See M. Harmon, W. Ferrell, & J. Franklin, "Effects on Carbon Storage of Conversion of Old-Growth Forests to Young Forests," 247 Science, 9 February 1990, p. 699.

<sup>78</sup> See IPCC Response Strategies Working Group, "Methane Emissions and Opportunities for Control," coordinated by Japan Environment Agency and U.S. EPA (September 1990).



Then, if emissions limits are warranted, a comprehensive approach can be phased in as other actions (e.g. forestry agreement) are integrated, and as the inclusion of harder-to-monitor sources and sinks becomes manageable. Although it is vital to begin with as fully comprehensive an approach as possible, an approach that is substantially comprehensive, in principle covering all RATGs, sources and sinks, could be supplemented with additional items as research and data brought them to a practical stage.

B. "The Global Warming Potential Index is uncertain."

There is emerging international consensus that the scientific fundamentals are sound. Although uncertainties remain in the index values, relating principally to the residence times of gases such as CO<sub>2</sub> and N<sub>2</sub>O, the IPCC found general acceptance for its GWP method; and the consensus of an international workshop on GWP Indices organized by NOAA, EPA, NASA, UKDOE and others in Boulder in November 1990 was that although these uncertainties require urgent attention, they do not warrant abandoning the index. Some of the estimates in the GWP index are expected to change as new research is undertaken. For example, recent work shows that the lifetime of CH<sub>4</sub> is 12.5, not 10, raising the GWP of CH<sub>4</sub>. The residence time of CO<sub>2</sub> is an estimate because carbon cycles between the ocean and atmosphere every 5-10 years, ultimately sequestered much later. This estimate will probably change as research proceeds. Methodological suggestions may also be made to improve the index.

For practical policy purposes, some index is much better than no index. The major choice is between no index (a piecemeal approach) and a good index; the choice between a good index and a near-flawless index is something more of a luxury. A good but imperfect index could serve well and then be amended later. Absolute precision is not necessary for practical uses, such as providing general guidance to decisionmakers, and affording them the flexibility to select a mix of response options among the several RATGs.

C. "Other discrete actions will have already been taken."

It is inevitable that other discrete actions will already have been taken by the time any climate agreement is signed. These include limits on CFCs in the Montreal Protocol, and could include forthcoming agreements on forestry and on VOCs.

Any international agreement employing the comprehensive approach would be constructed out of a number of institutional building blocks: the several international accords and national actions contemplated or already in place, each of which addresses



a discrete term in the global change equation. Related national actions would similarly be recognized, to avoid giving disincentives to useful measures that nations wish to take for other reasons. Indeed, these actions could be recognized in the convention, to provide incentives in advance for nations to take actions justified on other grounds that also address net RATG emissions.

D. "CFCs should not be included in comprehensive basket."

First, all anthropogenic substances contributing to radiative forcing should be included. Use of CFCs and CFC substitutes (HCFCs, HFCs) in the future may be quite important to radiative forcing, but the Montreal Protocol does not account for these impacts.<sup>79</sup> Failing to address these radiatively active gases in the climate context could invite perverse environmental results. Far from any "double counting," such an approach would account for the climate impacts of CFCs that the Montreal Protocol omits.

Second, it should be clear that a comprehensive approach to climate change would not allow nations to violate their obligations under the Montreal Protocol. At the same time, reductions more ambitious than required by the Montreal Protocol -- faster reductions, or reductions in other uncontrolled substances, or reductions achieved in nonparty nations -- could earn credit under the climate agreement; this would provide supportive incentives to phase out ozone-depleting substances even more quickly. Consider the incentive effects of the following options for addressing CFCs in an RATG agreement:

- (a) not giving credit for any limitation of CFCs and halons;
- (b) giving credit for limitations of CFCs and halons, to the extent they go beyond the limits required under the Montreal Protocol, and/or for limitation of ozone depleting substances that are also RATGs but that are not covered by the Montreal Protocol; and
- (c) giving credit for all limitation of CFCs and halons to the extent that they are RATGs.

Each of these options would have different effects on CFC consumption. Option (a), no credit, would provide no additional

---

<sup>79</sup> See Donald A. Fisher, et al., "Model Calculations of the Relative Effects of CFCs and their Replacements on Stratospheric Ozone," 344 Nature 508 (April 5, 1990); and Fisher, et al., "Model Calculations of the Relative Effects of CFCs and Their Replacements on Global Warming," 344 Nature 523 (April 5, 1990).



incentive to nations producing CFCs and halons to achieve further reductions beyond required limits. Option (b) would provide such an incentive, but by disallowing credit once the limitation is covered by the Montreal Protocol, option (b) would perversely discourage further expansions of the Montreal Protocol. And option (c) would provide such an incentive as well as recognize the value to potential global climate change of limits on CFCs and halons under the Montreal Protocol.

Third, some nations are doing more to reduce global CFCs than others, at their own expense, and their contribution should be recognized.

Fourth, excluding emissions reductions already covered by the Montreal Protocol would reduce the likelihood of attracting new parties to the Montreal Protocol: nations who are not now parties to the Montreal Protocol would face disincentives to joining the Protocol if joining meant that their CFC reductions lost credit under the climate agreement.

Fifth, there is an existing reservoir of CFCs and halons trapped in such containers as abandoned refrigerators. Leaks of such CFCs and halons constitute both ODP and RATG emissions, but are not covered by the Montreal Protocol. Giving credit for reductions in these CFCs would provide helpful incentives to store or recycle such gases safely.

E. "A comprehensive approach is complex and unworkable."

First, a comprehensive approach is not complex or unworkable. A comprehensive approach to research and monitoring is not only workable, it is the only practical approach. As an approach to any agreed emissions limitations, the Montreal Protocol has quite successfully demonstrated the feasibility of employing a multi-gas approach with an index of gases' relative impacts on the environment.

Second, as experience with traditional environmental issues shows, adopting a piecemeal approach means scrambling to redress unintended shifts and dysfunctions. The reality of shifts in traditional environmental contexts, and the potential for shifts in the climate context, elaborated in Chapter V, should indicate the serious workability problems facing a piecemeal approach.

Third, a comprehensive approach would ease the workability and complexity of any agreed emissions limits, by affording economic and institutional flexibility to nations to design their own best mix of response options. Piecemeal measures might be "easier said than done": easier to write down on paper, but harder for diverse nations to implement in light of



their diverse circumstances, needs and capabilities. Further, the comprehensive approach avoids the complex, cumbersome, and bureaucratized central determination of precise uniform gas-by-gas or source-by-source emissions targets, or selection of uniform "best available control technology," some or all of which would likely be called for under a piecemeal approach.

F. "We can't afford to wait for a comprehensive approach; we need to do what we can now to address CO2."

It might be argued by some that employment of the "comprehensive" approach could add delay to the process of reaching international agreement on global climate change issues. Some say that the fastest approach is to adopt protocols quickly for substances we can agree on now, and then proceed to thornier issues as we go.

First, development of a comprehensive approach does not mean delay. It is ready for implementation today in the framework convention, to define the scope and key elements of research and monitoring.

Second, if emissions limits are warranted, a comprehensive approach can be phased in as other actions (e.g. forestry agreement) are integrated, and as the inclusion of harder-to-monitor sources and sinks becomes manageable. Although it is vital to begin with as fully comprehensive an approach as possible, an approach that is substantially comprehensive, in principle covering all RATGs, sources and sinks, could be supplemented with additional items as research and data brought them to a practical stage.

Third, given its environmental and economic advantages, taking the time to develop a comprehensive approach is worthwhile. A piecemeal approach would mean environmental frustration and dysfunction, due to such defects as the potential for unintended shifts of residuals (see Chapter V); adopting a piecemeal approach sooner would probably not be a big improvement. A comprehensive approach could achieve better overall environmental protection than a piecemeal approach, even if it does take slightly longer to achieve than the first single-gas protocol would take.

Fourth, if there is agreement that response measures are warranted, use of a comprehensive approach to policy measures could in fact advance the date of agreement because (as discussed in Chapter VI) it raises the likelihood of broad consensus by eliminating the divisive inequitable effects of a piecemeal approach. Under almost any piecemeal approach, some party would be disproportionately burdened, and would be likely to block



effective agreement; a comprehensive approach would ease the way to equitable and sober consideration of response options.

Fifth, the suggestion that we ought to "do what we can now" is generally incorrect. As discussed extensively under Section A of this Chapter and Section C of Chapter VI, it is better to develop a sound approach at the outset than to launch an approach that is likely to fail at great cost. The framework needs to begin as a comprehensive approach, because starting with a piecemeal approach will likely leave it entrenched, rather than encouraging evolution toward a comprehensive approach. Those who are favored by the initial piecemeal approach would try to block any attempts to broaden its scope.

Sixth, many nations are already taking action. These steps should be accounted for and recognized through a comprehensive approach.

Seventh, a comprehensive approach makes better use of scarce resources, because it achieves results at less cost (see Chapter VI) and because it maximizes the environmental benefit for any investment of social resources. It thus better provides for sustainable development, which requires both effective and efficient policies since environmental protection ultimately depends on the resources that economic growth provides.

Finally, a comprehensive approach does not prevent action. Nations who wish to limit net emissions of any of the range of trace gases may do so now; indeed taking a comprehensive approach broadens the set of opportunities that nations have to act now to address potential climate change.



### Chapter VIII: Market-based Incentives

If any emissions limitations are deemed warranted and agreed to, they should allow nations the opportunity to employ, at their voluntary discretion, market-based incentives in implementation. We have learned a great deal about the drawbacks of traditional "command-and-control" regulatory approaches: by mandating uniform adoption of centrally chosen abatement techniques, they raise costs, discourage innovation and resource use efficiency, and raise administrative burdens. The virtues of market-based economic incentives for environmental protection are now increasingly well-recognized. The common feature of the new tools is that they respond to market-failure -- such as excessive pollution -- by redirecting and harnessing market forces to correct the problem. They allow flexibility among market actors, promote decentralized decisionmaking about response tactics, further least-cost solutions by allowing those who can fix the problem most cheaply to do so most, and stimulate efficient resource use and innovation in technologies and practices.

#### A. Voluntary Use.

Any use of market-based incentives should be at the voluntary election of the nation or nations involved. Domestically, each nation should have the option of employing any implementation mechanisms it prefers. These may include technology development, market-based incentives such as tradeable emissions allowances or fees, conventional regulations, technology standards, or other techniques. Any international agreement to respond to potential climate change should avoid impairing nations' freedom to choose their domestic policy tools.

Internationally, the use of market-based incentives would likewise be voluntary. For example, emissions trading is by its nature a voluntary enterprise. If the opportunity for international emissions trading is left open, it would mean that two or more nations could, at their voluntary election, cooperate on joint activities that together achieve their aggregate international obligation. It would simply allow a nation to achieve its goals abroad as well as at home. Similarly, a grouping of a region of nations, or a grouping of similarly interested nations, could elect to allow trading -- cooperative joint efforts to accomplish aggregate emissions goals -- among the member nations. No nation would be obliged to participate in any mandatory trading "system."

Market-based incentives could be employed under a single-gas approach or a comprehensive approach. Their advantages would be maximized when coupled with a comprehensive approach, since the flexibility of choices among gases, sources,



sinks, and location of investments would magnify the economic and incentive gains.

B. Examining current government interventions.

Before devising new policies, the first step in a market-based approach should be to examine current government policies and their effects on markets relevant to global change. What are their effects on the inputs to global change, and on the ability to adapt to any global change? On the input side, it is often government policies that subsidize activities in the energy, agricultural and forestry sectors and thereby increase net emissions of trace gases. These include counterproductive agricultural price supports and other policies that induce excess crop planting and unduly intensive use of nitrogenous fertilizers, adding to nitrous oxide emissions as well as erecting trade barriers. And they include rules that needlessly encourage even below-cost forest clearing, reducing carbon sinks.<sup>80</sup> On the adaptation side, policies that prevent the development of efficient markets for natural resources -- such as water -- may undermine the incentives that would be provided to induce conservation if global change put pressure on supplies. Better operation of private markets, on both the input and adaptation side, could help address climate change without major social expenditure.

C. Harnessing market forces toward environmental progress: U.S. experience.

Where market failures demand policy interventions, market-based tools can provide the best response options. Fees, tradeable allowances, and deposit-refund programs have demonstrated success in several important environmental applications, including the tradeable credits program used to phase out lead in gasoline -- achieved at about half the cost of a traditional regulatory program (amounting to savings of hundreds of millions of dollars). Both fees and tradeable allowances are now being used in the U.S. program to phase out CFCs under the Montreal Protocol. And tradeable allowances will be employed in the acid rain reduction provisions of the new Clean Air Act, with projected national savings of \$1 billion annually as compared to a command-and-control program.

The use of market-based instruments for environmental protection is not just the stuff of theory; it is already the

---

<sup>80</sup>See, e.g., Randall O'Toole, Reforming the Forest Service (1989); Robert Repetto, "Deforestation in the Tropics," 262 Scientific American, April 1990, p. 36.



reality of practical application in the United States and elsewhere. In several areas of environmental policy, market-based instruments such as tradeable allowances, fees, and deposit-refund systems are in place and have been operating with general (and often great) success.

The attractiveness of market-based economic instruments relates to the goal of environmental policy interventions: to correct failures of private markets to achieve society's environmental goals. The background presumption is that private markets will provide the goods and services that consumers desire. But private markets may provide inadequate environmental protection when environmental values are "externalities" not adequately reflected in the prices consumers pay for goods and services, or when environmental values are "public goods" from which all individuals benefit but in which no individual has an adequate incentive to invest.

In remedying such market failures, governments (the United States included) have traditionally employed "command-and-control" regulations. Such regulation relies on uniform, inflexible, technology-based standards that result in high compliance costs, restrict innovation, discourage efficient use of resources, and require detailed central planning of economic activity. While some of these regulatory controls have been initially effective in limiting environmental degradation, they have also proved to be costly and burdensome. Because the cost of controlling pollution varies among those subject to regulation, a command-and-control policy requiring them all to meet the same target, or to install the same technology, means that some could have achieved the same environmental protection outcome through less costly means. Society is consequently forced to pay more for environmental protection than it needs to, wasting resources and potentially arousing resistance to further environmental policy measures. In the longer run, command-and-control regulation deters innovation by selecting a chosen technology and giving no reward to those who devise a better techniques; this in turn weakens the ability of command-and-control regulation to prevent environmental degradation effectively.

Since the underlying problem is that private markets are operating imperfectly, the better approach for government action will often be to "reconstitute" the market: to orient it toward providing incentives that promote the desired environmental outcome. By revising the market's own system of pricing and allocating environmental protection responsibilities, market-based mechanisms turn the power of the marketplace -- the indefatigable creativity of diverse and flexible responses by motivated market actors -- to environmental advantage. Overall social costs are reduced because those who can prevent degradation most cheaply have the most incentive to do so.



Environmental protection is advanced as the incentives spur innovation in technologies and processes, and as efficient use of resources (such as conservation of fuels) is put on equal footing with installation of control technology.

Among the several types of economic instruments that might be used to implement environmental policy, current applications have generally employed a few basic techniques: fees, tradeable allowances (also called marketable permits), and a hybrid form called deposit-refund systems.

A fee can be attached to each unit of emissions, effectively forcing the emitter to "internalize" the cost that the emissions impose on society. Each emitter reduces emissions to the point that its costs of control become as expensive as paying the fee; this point will vary for each emitter, but the aggregate emissions reduction will correspond to the size of the fee exacted.

Under tradeable allowances, a constraint is imposed on the total quantity of emissions, allowances adding up to that total are issued, and emitters are allowed to reallocate allowances among themselves. The aggregate emissions cannot exceed the total level set, but the amount controlled by any individual emitter may vary -- provided that it must hold allowances for each unit of emissions, or face heavy penalties. Those who can control emissions more cheaply free up excess allowances to sell at a profit, while those for whom control is more expensive purchase allowances. The market price of the allowances is effectively similar to a fee on emissions, forcing purchasers to internalize the costs of their excess emissions.

A deposit-refund system is like a fee with a rebate: those who generate a waste, or purchase a product, must pay a deposit on the item; when they return the item for proper treatment, they receive a refund. This arrangement provides an incentive for proper handling, whereas a mandatory return rule could induce illegal disposal to avoid the costs of return.

The United States has used each of these market-based mechanisms as tools to implement environmental policy. This section provides a picture of the great diversity of contexts in which these tools are being applied, and the general features of each program.<sup>81</sup>

---

<sup>81</sup> This discussion draws heavily on Bruce Ackerman and Richard Stewart, "Reforming Environmental Law: The Democratic Case for Market Incentives," 13 Colum. J. Envtl. L. 171 (1988); Robert Hahn and Gordon Hester, "Marketable Permits: Lessons for Theory and Practice," 16 Ecol. L. Q. 361 (1989); Richard Stewart, "Current Experiments with Economic Instruments in Environmental Policy," paper presented at the EDF/AER\*X/USSR Academy of Sciences "Soviet-American Conference on Economic (continued...)



1. Current programs.

Emissions trading under the ambient air quality rules of the Clean Air Act: bubbles, netting, and offsets. Under the Clean Air Act, each region of the country must attain ambient air quality standards. Existing, modified, and new sources of emissions are all required to employ emissions controls. Starting in the late 1970s and increasingly in the last decade, the U.S. Environmental Protection Agency (EPA) has employed several different emissions trading programs: "Offsets" allow new sources of emissions to be added to an area (provided they employ stringent control technology) so long as they obtain corresponding decreases in emissions from existing sources in the same area. "Netting" allows an existing source to add a modification that produces additional emissions, without having to install the most stringent emissions control technology, if it obtains a corresponding decrease in emissions from other parts of the same unit. "Bubbles" allow existing plants with emissions emanating from multiple units (such as several smokestacks) to reallocate emissions among the sites within the plant, and existing plants to reallocate emissions among a set of plants, so long as total emissions do not increase. In addition, a banking program lets existing sources store excess reductions in emissions for future use.

Experience has been different under each of these programs, but in general, there have been significant cost savings over traditional regulations. The netting and bubble programs, for example, achieved savings estimated at several billion dollars in the first seven years of the program. And these substantial savings have been obtained despite the fact that the trading program is a modest modification to a traditional, command-and-control technology design regulatory program. Meanwhile, no reduction in environmental quality has been observed; there has been no increase in the aggregate emissions level.

Lead phasedown: content reduction credits. Also under the Clean Air Act, the EPA issued regulations reducing the allowable lead content of gasoline. In 1982 EPA instituted limits on lead content and permitted trading within and among refiners: leaded gasoline producers and importers could transfer (i.e., buy and sell) lead content credits freely among themselves through 1986, or could apply such credits to their own gasoline. But such credits expired quarterly if unused. In 1985, EPA

---

81(...continued)

Instruments for Environmental Protection," Washington D.C., November 12, 1990; and James Tripp and Daniel Dudek, "Institutional Guidelines for Designing Successful Transferable Rights Programs," 6 Yale J. Regulation 369 (1989).



substantially reduced the lead content limit further; the content was required to decline, in phases, from 1.10 grams of lead per gallon (gpg) to no more than 0.10 gpg by the end of 1985. To provide leaded gasoline producers and importers with some flexibility in complying with the new limits, EPA also issued regulations in 1985 permitting producers and importers whose gasoline in 1985 contained less lead per gallon than the applicable standard, to "bank" lead content credits (i.e., to avoid the expiration of credits). The "banking" regulations then permitted gasoline producers and importers to "withdraw" those lead content credits through the end of 1987 and to apply them to help meet the new, more stringent lead content standards that took effect in 1985.

The banking and trading system helped the industry as a whole to comply with the new lead limits, while ensuring that the total amount of lead content did not exceed the maximum that otherwise would have been allowed under the lead content standards in the absence of the banking provisions. Data indicate that banking and trading were active, and that they resulted in substantial cost savings (on the order of hundreds of millions of dollars over the few years of the program).

The design of the lead phasedown facilitated widespread trading. Firms were not required to apply to the EPA for permission to enter into trades; they simply reported their trades to the government, as part of their regularly required reports of the lead content in their gasoline. Each firm was simply required to have a net balance of lead content credits greater than or equal to zero in each quarter. In addition, because gasoline refiners and importers were accustomed to trading feedstocks and other commodities with each other, trades in lead content credits did not require new information networks. In sum, the lead phasedown was highly successful.

CFCs reduction: production allowances. Both trading and taxes are being used in the effort to phase out chlorofluorocarbons (CFCs) in order to protect the stratospheric ozone layer. Internationally, the 1987 Montreal Protocol obliges each nation to cut in half its consumption of CFCs by 2000; the 1990 update of the Protocol accelerates that schedule to a total phaseout by 2000. The Protocol allows a small amount of trading among nations in CFC production, a flexibility that was expanded in the 1990 update. To date little if any trading under this provision has occurred, probably because the Protocol explicitly constrains the extent of the trading, and also because trading is only allowed in production (i.e. in the physical location of production facilities) and not in consumption (defined as production plus imports less exports).

Domestically, in order to implement the first phase of the 1987 Montreal Protocol and the national legislation following from it, the U.S. EPA has issued regulations requiring the 50% phaseout by 2000 and implementing the phaseout by issuing allowances to each producer and importer of CFCs. These



allowances may be traded among producers, importers and other interested parties. EPA is able to monitor production and imports of CFCs, and to keep track of allowance trades. Producers are aware of potential buyers and sellers and can trade allowances freely. But the small number of producers and importers may limit the number of trades that actually occur.

It is sometimes assumed that market-based instruments are a substitute for tough enforcement programs, which they are not. As indicated earlier, tradeable allowance systems depend on preventing emitters from emitting more than the allowances they hold. The CFCs program is a good example of our vigorous enforcement efforts: this past summer we brought the first enforcement actions by any government worldwide, so far as we know, to enforce compliance with obligations under the Montreal Protocol. We sued six companies for importing CFCs without obtaining allowances; the violators were required to purchase allowances on the open market and in addition to pay penalties.

In addition to issuing CFC allowances, the United States has imposed an excise tax on CFC production and importation. Like the allowance trading system, this tax will encourage the transition to higher-priced substitutes for CFCs. The tax is a multiple of the ODP value for each CFC, calibrating the incentive to the environmental impact of the substance.

An important issue in protecting the earth's ozone layer is the large reservoir of CFCs remaining stored in coolant systems and other end uses. The tax and tradeable allowance systems will provide some incentives to recover and recycle old CFCs, but a direct refund might be offered to encourage more recovery.

#### Pinelands development: tradeable development rights.

A somewhat different kind of allowance approach has been used successfully by the State of New Jersey to regulate development of the Pinelands, a forest zone the State wishes to protect from excessive development. Here the allowances are not for emissions, but for rights to develop certain property. Property in parts of the Pinelands is slated for preservation, and the owners of that property may agree to be prohibited from developing their land. In return, they are issued "transferable development rights" (TDRs) which they may sell to others wishing to develop land in the other areas of the Pinelands. Different amounts of TDRs are issued to each owner, depending on the value to society of preserving that owner's property. In areas in which development is permitted, landowners must hold TDRs to develop their property. Thus, the total amount of development in the Pinelands is capped, and the regional distribution is partly restricted; but the precise allocation of development on permissible properties is left to the market for TDRs. In addition, no current landowner is entirely deprived of the former market value of his or her land, because those who are barred from developing their own land receive TDRs to sell to others. The government has established a TDR exchange to facilitate



trades: the exchange buys TDRs from willing sellers and sells them to interested buyers.

Fox River water quality: discharge renegotiations.

Under the Clean Water Act, sources of discharges into water supplies must meet emissions limits to achieve water quality standards. The State of Wisconsin adopted a discharge limit system for the Fox River that set the limit for each source, but also permitted sources to devise new discharge limits, by mutual agreement, so long as the total discharge did not rise. In principle, the plan implements a market in transferable emissions allowances. In practice, however, the system has proved cumbersome. Sources hold five-year permits from the state, and trades may expire at the close of a permit cycle, impairing their use for reallocations that involve long-term investments in capital equipment. No allowances or credits are actually issued to sources; instead, each agreement between sources must be submitted for approval to the state agency. Parties must demonstrate to the state that they "need" to make changes in their permits. Review by the agency can be complex and time-consuming. And there is no broker to help arrange trades. Thus, transaction costs are high and the market is sluggish. Agency review of proposed trades is deemed necessary, moreover, by the fact that agreements between sources can yield very low discharges of toxic substances in one local area and very high discharges of toxics in another, potentially placing too great an ecological burden on the latter area. Hence the spectrum of possible trades is limited, and few trades have occurred.

Dillon Reservoir water quality: point/nonpoint trades.

In the state of Colorado, discharges from economic activity were endangering the drinking water supplies in the Dillon Reservoir. Emissions came from both point sources (e.g. factory discharge pipes) and nonpoint sources (e.g. runoff). The government issued annual discharge allowances to all sources. It then required that sources may increase their discharges only if they acquire allowances from nonpoint sources, at a ratio of 2:1. That is, for each pound of discharges a source wishes to add, it must reduce discharges by two pounds from nonpoint sources. Because control of point sources is about seven times as expensive as control of nonpoint sources, the 2:1 trading ratio leaves dischargers considerable room for cost-saving trades. Thus, trading will likely both save costs and reduce emissions. Although the program is just getting under way, observers expect active trading and significant cost savings.

Beverage containers: deposit-refunds. In order to reduce litter and encourage recycling of glass and aluminum beverage containers, several states have enacted "bottle bills." These laws institute a deposit-refund system for bottles and cans, in which a deposit (typically 5 cents per container) is charged at the point of purchase and is refunded upon delivery of



the containers to a retailer or recycling depot. Although these programs may reduce litter, they typically charge the same deposit regardless of the type of container (e.g. metal or plastic) and thus fail to provide incentives to consumers to choose the material whose disposal is least costly to society. And the social desirability of these deposit-refund systems depends on how much time consumers must spend returning the containers; curbside pickup programs could be preferable.

Debt-for-nature swaps: international environmental trading. Arrangements in which banks forgive debt in return for the debtor's agreement to conserve natural resources, dubbed "debt-for-nature swaps," are a kind of trading applied to environmental protection. These ad hoc arrangements are not a government "program"; rather they illustrate that private markets can offer mutual benefits to the trading of one asset (debt) for another (environmental protection). A few such swaps have occurred to date. These swaps might serve as a model for more institutionalized international trading on global environmental issues.

## 2. Programs about to be implemented.

Administration plan to reduce acid precipitation: tradeable allowances. The Bush Administration proposed, and Congress has just enacted, new Clean Air Act legislation to reduce emissions of materials that contribute to acid precipitation. A key feature of the Administration plan is the use of transferable emission allowances. The law sets a permanent cap on emissions of sulfur dioxide (SO<sub>2</sub>) (one of the main precursors of acid precipitation) from fossil fuel-burning electric utilities larger than 25 megawatts (the primary source of SO<sub>2</sub> emissions in the U.S.). Initially, annual emissions allowances will be issued to existing utilities in two phases according to a formula that multiplies each plant's historic energy capacity factor by a target average SO<sub>2</sub> emissions rate which is generally lower than the current actual average emissions rate. Under this formula, utilities operating plants with high emissions would not be allocated enough allowances to cover their emissions at historical levels.

To make up this allowance shortfall, which will amount to about 10 million tons of SO<sub>2</sub> per year, individual utilities could reduce their emissions by switching to cleaner fuels, installing additional emissions control equipment or taking conservation measures, or could purchase additional allowances; overall, the industry as a whole will reduce emissions by 10 million tons. Utilities that can afford to reduce their emissions below the target average emissions rate (i.e. below the number of allowances they have been allocated) will be able to sell those "extra" allowances as "credits" to other utilities for whom purchasing allowances is cheaper than investing in emissions



reductions. New entrants to the electricity industry can acquire allowances from existing utilities, or from occasional auctions of a small percentage of allowances reserved by the government.

The cost savings of this trading plan over a plan not employing trading are estimated at about one billion dollars per year or higher. This plan also creates a strong financial incentive for utilities to engage in energy conservation and technological innovation, whereas both would be discouraged by a rule requiring utilities to adopt specific emissions control mechanisms such as scrubbers.

Clam and quahog harvesting: individual transferable quotas. Traditionally, harvesting of surf clam and quahog (a related species) off the East coast of the U.S. have been capped at an aggregate amount; but individual boats' quahog fishing had been otherwise generally unregulated while certain aspects of individual boats' surf clam fishing (such as the frequency of outings and their length) had been carefully regulated. A new program has been developed to employ trading to allocate harvesting activities more efficiently. Under the recent "Amendment 8" to the Fisheries Management Plan for the Mid-Atlantic region of the United States, a system of "individual transferable quotas" (ITQs) for clams and quahogs will be created, with each ITQ representing a percentage of each market. They are initially to be issued to each vessel based on the vessel's historical fishing. The ITQs may then be traded among vessels. This plan has recently been challenged on a variety of legal grounds by plaintiffs including vessel owners and seafood processors.

Mobile sources: averaging, banking and trading. Mobile sources (vehicles) consume fuel and emit pollutants, and trading is being employed in programs to limit both of these activities.

A kind of "internal" trading (trading within a firm) is already allowed under the rules requiring vehicles to attain fuel economy (miles per gallon) standards. The government might have required every individual vehicle to achieve a specified minimum fuel economy standard. Instead, the "Corporate Average Fuel Economy" (CAFE) rules govern the average efficiency of each manufacturer's entire fleet in each model year. This gives the manufacturer flexibility to reach the same aggregate fuel economy while varying the characteristics of each vehicle to suit the spectrum of consumer needs and tastes.

Even more flexibility could be obtained if fuel economy achievements could be tradeable among manufacturers: if one manufacturer who achieved a fleet average lower than the applicable CAFE rule could sell its excess as a "credit" to another manufacturer whose fleet exceeded the rule.

Along these lines, EPA has recently revised its Clean Air Act program governing the particulate and nitrogen oxides emissions of heavy-duty truck engines. For several years EPA has set an average emissions standard for the line of truck engines



produced by each manufacturer, thus affording each manufacturer the internal flexibility to make a range of engines so long as their average cleanliness meets the standard (similar to the CAFE program for fuel efficiency). In its new regulation, EPA now allows emissions trading among manufacturers and banking over time. EPA provides that a manufacturer whose line of engines emits less on average than the standard will earn "credits" which can be banked for application to future model years, or traded to other engine manufacturers. The greatest emissions reductions will be achieved by those manufacturers who can do so at least cost, reducing the overall social cost of the program. And manufacturers will have additional incentives to reduce emissions in order to generate credits to sell at a profit. In an effort to provide assurance that the trading and banking program will not impair environmental protection, EPA is providing that credits will be redeemable at 80% of their face value, reducing by 20% the emissions allowed upon each trade, but also reducing somewhat the attractiveness of investment in additional emissions reductions. EPA projects that the profits from credit sales will still be sufficient to stimulate trades and emissions reductions even with the 20% discount.

Other air quality programs. The 1990 Clean Air Act amendments call for the establishment of other programs in which the trading of marketable allowances is envisioned. One such program is the clean fuel vehicles program, requiring both manufacture of vehicles capable of using cleaner fuels, and purchase of such vehicles by owners of vehicle fleets. Under each part of the program, those who make or purchase more clean fuels vehicles would receive tradeable credits. Another program requires sale of cleaner fuels, including cleaner gasoline, reformulated gasoline, and oxygenated fuels, to reduce VOCs, CO, and toxic air pollutants; it awards tradeable credits for those who exceed production targets.

### 3. Programs under discussion.

Municipal solid waste. The large volume of municipal solid wastes is prompting concern that landfill capacity will run out. As landfills have become scarce, some of the waste stream has been diverted toward incineration, but that route can pose air pollution problems and generates incinerator ash. Another option might be water disposal in lakes or seas, but tight rules already constrain that possibility. Command-and-control regulation to specify the technology and design of landfills and incinerators can offer some improvements in those facilities, but is not likely to affect the total stream of solid waste directly, and can simply shift wastes from land disposal to air incineration. Mandating that residents separate materials for recycling can also be useful, but does not assure a market for



the recyclable materials and does not directly discourage generation of waste by residents.

One proposal to address these problems is to impose a cost on the generation of solid waste that reflects its social cost of disposal. Such a fee would provide an incentive to reduce the total volume of wastes produced, not just to shift it from land to air to water. The harder questions are how to set the fee and where to assess it. The marginal social cost of disposal may vary from one community to another, so the fee may need to vary across localities, but the products that become solid waste are generally produced and sold in a national retail market. Assessing the fee at the curbside (the point where households put their trash out for pickup) can be successful, as it has been in cities such as Seattle, Washington and Perkasio, Pennsylvania, where a fee is assessed per container (barrel or bag) on the trash that households set out for pickup. But these programs have some difficulty calibrating the fee to the unique disposal costs of each specific material being discarded. Another option<sup>82</sup> is to assess the fee at the point of purchase, by charging a disposal cost on each retail item according to its ingredients and packaging, and reflecting that cost on the receipt the customer receives from the store. This option is facilitated by the use of computerized cash registers and optical scanners that read a "bar code" printed on the package; the disposal fee can then be programmed into the cash register's computerized price list, and revised periodically or by locality to reflect changing costs. Optical scanners and computerized cash registers are now in use in over half of the retail supermarkets in the U.S. But this option has the drawback that it is difficult to predict in advance how the product will be handled after purchase -- discarded, incinerated, or recycled. Perhaps some combination of local curbside fees and point-of-purchase fees would perform best.

Hazardous wastes. For several types of hazardous wastes, such as lead-acid batteries and solvents, it is important not only to reduce total quantities generated but also to ensure that whatever is generated is carefully handled. Prohibiting landfill disposal of such substances, or mandating disposal in certain designated sites, can lead to "midnight dumping" and other socially damaging evasive tactics. An alternative, market-based option is the use of deposit-refund systems to encourage proper disposal. A deposit is charged on the sale of the item, which is refunded when the item is returned to the retailer or treatment facility. This gives the purchaser an incentive to return the waste properly, not to discard it randomly. Deposit-refund systems for lead-acid batteries are now operated by the

---

<sup>82</sup> See Peter Menell, "Beyond the Throw-Away Society: An Incentive Approach to Regulating Municipal Solid Waste," 17 Ecol. L.Q. 655 (1990).



states of Maine and Rhode Island. One possible difficulty with offering a refund on returned batteries is that it might encourage theft of batteries; various measures, such as lockable battery cases, or requiring a receipt to be presented with the battery, could be used to deter theft.

D. Harnessing market forces to address climate change.

If the threat of global change is a market failure worthy of policy intervention, then market-based incentive techniques are especially well-suited to implementing limitation measures for trace gases contributing to global change. The current U.S. policy to phase out CFCs is a prime example of this approach. Because trace gas emissions arise from so many diverse and pervasive sources, the costs of abatement are bound to vary widely among emitters. Market-based mechanisms use that variation to social advantage by imposing some restraint on total emissions -- a limit on the net quantity emitted, or a fee on each unit emitted -- but then letting the market allocate the burden of mitigative measures to those who can most easily shoulder it. Because the trace gases mix essentially globally and have essentially only global impacts, the possibility under market-based incentives that the spatial distribution of emissions may become uneven -- called "hotspots" in the context of toxic substances -- would not be of concern.

In the context of limiting inputs to global change, two main economic instruments have been suggested: tradeable emissions allowances, and emissions fees. Both instruments hold the potential for achieving environmental goals at least cost. Tradeable allowances set a total limit on net emissions, issue that sum of allowances to emitters, and let emitters trade them. Those for whom emissions reductions or sink expansions are relatively more expensive will buy allowances, while those who can achieve them cheaply will sell allowances. This gives an incentive to each emitter to develop new means of limiting emissions at less cost than its competitors, so that it can sell its allowances at a profit. The choice of response tactics -- emissions controls, efficient use of fuels and other inputs, and innovation of new emissions limitations techniques -- is left to the emitter. The market allocates abatement actions to those who do so at least cost, reducing the overall cost to society.

Trading could be employed domestically (within a nation) by nations taking steps to limit their emissions of trace gases, as we are using trading in the new Clean Air Act acid



deposition program and in the phaseout of CFCs.<sup>83</sup> Thus, any nation that decided to limit its emissions of one or more RATGs could allow emitters within its borders to trade their emissions allowances.

Allowing the opportunity for voluntary reallocations among nations of any agreed international obligations would also be advantageous. Such trades could consist of informal, bilateral reallocations of any obligations to limit net emissions. One nation could satisfy such obligations by investing in response actions in another, with the latter's consent. Any such reallocations would be entirely at the discretion of the participating nations; no nation would be obliged to participate. For example, nation A might approach nation B with a proposal: A will provide new energy technology or agricultural research to B, if B will assign to A some of the resulting emissions reductions. Given the significant international variations in the marginal costs of RATG abatement, the opportunity for such trades would likely enable the world economy to realize substantial cost savings. Limited international CFCs trading of this sort is now authorized under the Montreal Protocol, but it remains to be seen whether the Protocol's strictures on trading will leave room for market activities.

Such trading would also serve as a market-based, decentralized vehicle for introducing needed technology into the developing world. Developing countries could exchange excess emissions allowances for low- or non-RATG-emitting technology from industrialized nations; thus, the developing nation would receive needed resources and a means to pursue economic growth without emitting RATGs. This system would reduce global emissions, while pointing technology toward those who needed it most and stimulating innovation by industrialized nations of technologies useful in developing nations. At the same time, this framework could obviate creation of a heavily bureaucratized, centralized regulatory authority and technology assistance fund that would be less efficient at routing needed resources and technology to recipients.

Emissions fees are another important option. The fee could be calibrated to the environmental impacts index value of the net emissions activity. Like emissions trading, emissions fees offer a least-cost solution that promotes innovation and efficient resource use. Such a plan could make excellent sense

---

<sup>83</sup> See U.S. EPA, "Protection of Stratospheric Ozone," 53 Fed. Reg. 30,566 (1988) (to be codified at 40 C.F.R. pt. 82) (Final Rule) (capping CFC production with marketable permits); 53 Fed. Reg. 30,604 (1988) (Advance Notice of Proposed Rulemaking) (proposing allocation of permits).



domestically, especially where the focus is on specifying the cost of a limitation program more precisely than the quantity of emissions avoided, or where revenue raising is a major goal. Indeed, the U.S. is employing fees on CFCs in addition to tradeable allowances. International application of a fee would raise many more difficult questions: Would nations cede their sovereignty to an international tax authority? How would the fee be set in light of varying effective marginal tax rates, and diverse taxation structures, across nations? How would the potentially enormous revenues raised be allotted and expended?

Market-based incentives could also be used to encourage efficient adaptation practices. Long-range investments, such as coastal construction or water use planning, might, because of market failures or other institutional failures, be undertaken without giving appropriate weight to any global change risks (such as rising sea levels or shifting precipitation). Such failures might be addressed by informational or incentive-based policies, such as by requiring coastal construction to purchase subsidence (coastal erosion) insurance, or by fostering a market in water resources that provides incentives for efficient use and long-range risk management.



## CONCLUSION

### Toward a Comprehensive Approach

Addressing the potential problems of global climate change will require creative thinking. Treating the causal factors of global climate change in a piecemeal fashion, gas-by-gas and source-by-source, would ignore the science of climate, jeopardize sound environmental protection, squander scarce resources, and impose inequitable burdens and unreasonably uniform requirements on nations with diverse needs and capabilities. Instead, a "comprehensive" approach to addressing potential global climate change, treating all radiatively active trace gases, their sources and sinks collectively, should be employed in any international agreements addressing potential climate change. Such a comprehensive approach provides a better understanding of human interactions with climate, and, if policy responses are deemed warranted, the means to achieve real environmental quality improvements while preserving economic and institutional flexibility.

Several steps could be taken to incorporate a comprehensive approach into the framework convention on climate change. As described earlier, the comprehensive approach has multiple applications. Each could be incorporated into the work of the IPCC, the convention, and any program the convention establishes. For example, the convention could charge the IPCC or other body to coordinate and assess work on the following:

Research strategy. The convention could advance integrated scientific and economics research on a comprehensive basis, ensuring attention to the sources, sinks, atmospheric properties, and socioeconomic and ecological impacts of all the relevant trace gases.

Monitoring. The convention could spur development of techniques and systems for comprehensive source and sink monitoring, such as cooperative international networks measuring emissions and uptake of all relevant trace gases. It could establish centers for data sharing, harmonizing methodologies, and research & development of new techniques.

International inventories. The convention could help build the capacity to estimate international net emissions of relevant trace gases, including baseline levels and changes due to policy actions. It could provide for national reporting, and for workshops to compare and improve data and methods.

Indices. The convention could continue the IPCC's cooperative development and refinement of indices. It could



charge the IPCC or other body to conduct regular assessments and to keep policy makers informed of developments.

Technology evaluation. The convention could employ a comprehensive approach to assess the net emissions impact of any technology transfer and financial assistance activities. This would provide guidance to maximize the environmental benefits of any such projects.

The convention could also:

Ensure a comprehensive framework for policy. It could provide that any policy discussion, any calls for "national plans," or any limitations obligations (if any, whether now or in the future), are (will be) defined in terms of a comprehensive approach.

Offer incentives through advance assurance. The convention could give advance assurance that current actions will receive credit against any future obligations, in accordance with a comprehensive approach. This would help avoid disincentives to nations taking actions justified on other grounds, which nations may hold in abeyance until credit for them is assured. Actions could include such measures as afforestation, energy conservation, and trace gas reductions, and both national and international programs.

Following a comprehensive approach in the framework convention on climate change would be a substantial scientific, environmental and economic advance in the effort to address complex environmental issues.



REFERENCES

Ackerman & Stewart, "Reforming Environmental Law," 37 Stan. L. Rev. 1333 (1985).

Ackerman, Bruce A. and Richard B. Stewart. "Reforming Environmental Law: The Democratic Case for Market Incentives," 13 Colum. J. Envtl. L. 171 (1988).

Barrett, Scott. "Economic Instruments for Managing Climate Change: A Survey and Analysis of Current Proposals." London Business School; prepared for BP International. Revised April 1990.

Barrett, Scott. "Pricing the Environment: The Economic and Environmental Consequences of a Carbon Tax." Economic Outlook, pp. 24-33. February 1990.

Barrett, Scott. "On the Nature and Significance of International Environmental Agreements." London Business School, May 1989.

Barrett, Scott. "The Problem of Global Environmental Protection," 6 Oxford Rev. Econ. Policy (no. 1) (198 ).

Bohm, Peter. "Efficiency Issues and the Montreal Protocol on CFCs." World Bank Working Paper No. 40, Environment Department, September 1990.

Bohm, Peter. "Mitigating Effects on Fuel Prices from Incomplete International Cooperation to Reduce CO2 Emissions." Draft December 1990.

Brady, Gordon L., Maloney, M. & Abbott, A. "Political Limits of the Market for "BAT Medallions." Cato Review of Business & Government Regulation, pp. 61-64 (Winter 1990).

Coburn, Leonard L. "Emissions Trading: A Market-Based Solution for Environmental Problems in the Electric Power Industry." 13th Annual International Conference, International Association for Energy Economics. Copenhagen, Denmark. June 19, 1990.

Cristofaro, Alex and Joel Scheraga. "Policy Implications of a Comprehensive Greenhouse Gas Budget." U.S. EPA, OPPE, draft September 1990.

Dudek, Daniel J. "A Short Discussion of Greenhouse Gas



Trading." Prepared for Climate Action Network Meeting, Stockholm, Sweden, August 31 - September 1, 1990.

Dudek, Daniel J. "International Trading in Greenhouse Gas Permits." Policy Paper prepared for Project 88 -- Round II, EDF, July 1990.

Dudek, Daniel J. "Lessons from U.S. Experiments in Environmental Reform." Paper presented at the international workshop on Institutional Design for Environmental Protection in Poland, Sept. 17-20, 1990.

Dudek, Daniel J. "Emissions Trading: Environmental Perestroika or Flimflam?" The Electricity Journal, pp. 32-43, November 1989.

Dudek, Daniel J. "Marketable Instruments for Managing Global Atmospheric Problems." Economic Frontiers in Environmental Policy, Annual Meeting of the Western Economics Association. Vancouver, British Columbia. July 7-11, 1987.

Dudek, Daniel J. and Alice LeBlanc. "Offsetting New CO2 Emissions: A Rational First Greenhouse Policy Step." 8 Contemporary Policy Issues 29 (July 1990).

Dudek, Daniel J., Alice M. LeBlanc, and Peter Miller, "SO2 and CO2: Consistent Policymaking in a Greenhouse," Environmental Defense Fund, New York, January 1990.

Dudek, Daniel J. and John Palmisano. "Emissions Trading: Why is this Thoroughbred Hobbled?" 13 Colum. J. Envtl. L. 217 (1988).

Eckaus, Richard S. "Comparing the Effects of Greenhouse Gas Emissions on Global Warming." MIT, Center for Energy Policy Research, November 1990.

Ellington, Rex T. and Meo, Mark. "Avoiding the Rat Gas Trap: The Development and Use of a Greenhouse Gas Emissions Index." AIChE National Meeting, Philadelphia, PA, August 20-23, 1989.

Fisher, Donald A.; Hales, Charles H.; Wang, Wei-Chyung; Ko, Malcolm K.W.; Dak Sze, N. "Model calculations of the relative effects of CFCs and their replacements on global warming." 344 Nature 523 (1990).

Fisher, Donald A.; Hales, Charles H.; Filkin, David L.; Ko, Malcolm K.W., Dak Sze, N.; Connell, Peter S.; Wuebbles, Donald J.; Isaksen, Ivar S.A. and Stordal, Frode. "Model Calculations of the Relative Effects of CFCs and their Replacements on Stratospheric Ozone." 344 Nature 508 (1990).



Gamache, Robert R. and Golomb, Dan. "The Relative Role of Methane and Carbon Dioxide in the Greenhouse Effect." Final Report, January 1990, submitted to American Gas Association.

Grubb, Michael. "International Marketable Emission Permits: Key Issues." Royal Institute of International Affairs, Paper prepared for IPCC/OECD workshop on Financial and Economic Measures as a response to climate change, Paris, April 1990.

Grubb, Michael. The Greenhouse Effect: Negotiating Targets. London: Royal Institute of International Affairs, 1989.

Hahn, Robert W. and Gordon L. Hester. "Marketable Permits: Lessons for Theory and Practice." 16 Ecol. L. Q. 361 (1989).

Hahn, Robert W. and Gordon L. Hester. "Where Did All the Markets Go? An Analysis of EPA's Emissions Trading Program." 6 Yale J. Regulation 109 (1989).

Hahn, "An Evaluation of Options for Reducing Hazardous Waste," 12 Harv. Envtl. L. Rev. 201 (1988).

Hahn, "Economic Prescription for Environmental Problems: How the Patient Followed the Doctor's Orders," 3 J. Econ. Persp. 95 (1989).

Hahn, "Marketable Permits: What's All the Fuss About?" 2 J. Pub. Policy 395 (1982).

Hahn, "The Political Economy of Environmental Regulation: Towards a Unifying Framework," 65 Public Choice 21 (1990).

Hahn & Noll, "Barriers to Implementing Tradable Air Pollution Permits: Problems of Regulatory Interactions," 1 Yale J. Regulation 63 (1983).

Hahn & Noll, "Designing a Market for Tradeable Emissions Permits," in Reform of Environmental Regulation (Magat ed. 1982).

Hahn & Noll, "Implementing Tradeable Emission Permits," in Reforming Social Regulation: Alternative Public Policy Strategies (1982).

Hahn, Robert & McGartland, Albert, "The Political Economy of Instrument Choice: An Examination of the U.S. Role in Implementing the Montreal Protocol," 83 Nw. U. L. Rev. 592 (1989).

Hahn, Robert & Axtell, Robert, "On the Presumed Superiority of Transferable Property Rights," AEI, paper delivered at the



Stanford Conference on Environmental Economics, Oct. 11-13, 1990 (draft 10/5/90).

Hahn, Robert & Stavins, Robert, "Incentive-Based Environmental Regulation: A New Era from an Old Idea?" John F. Kennedy School of Government, Harvard University, Discussion Paper 183D (draft June 19, 1990).

Haites, Erik and Tom Tietenberg. "Cost Effective Policy Responses to Global Warming." Barakat & Chamberlin, Toronto, and Colby College, Waterville Maine. Draft May 1990.

Intergovernmental Panel on Climate Change (IPCC), First Assessment Report (August 1990), and Climate Change: The IPCC Scientific Assessment, Cambridge University Press, 1990.

Lashof, Daniel A. and Ahuja, Dilip R. Relative Global Warming Potentials of Greenhouse Gas Emissions. 344 Nature 529 (1990).

Levander, Thomas. Memorandum: The Importance of Greenhouse Gases Other Than Carbon Dioxide and Other Possible Differences Between Various Fuels. National Energy Administration, Sweden, Sept. 14, 1989.

Levin, Michael H. and Barry S. Elman. "The Case for Environmental Incentives." Envtl. Forum (January/February 1990) at 7.

Marchant, Gary E. "Freezing CO2 Emissions: An Offset Policy for Slowing Global Warming." John F. Kennedy School of Government Policy Analysis Exercise for Kirkland & Ellis, Washington D.C., April 12, 1990.

Menell, Peter. "Beyond the Throw-Away Society: An Incentive Approach to Regulating Municipal Solid Waste." 17 Ecol. L. Q. 655 (1990).

Note, "Acid Rain, Emissions Trading and the Clean Air Act Amendments of 1989," 15 Colum. J. Env'tl. L. 329 (1990).

Ramanathan, V.; Callis, L.; Cess, R.; Hansen, J.; Isaksen, I.; Kuhn, W.; Lacis, A.; Luther, F.; Mahlman, J.; Reck, R.; and Schlesinger, M. "Climate-Chemical Interactions and Effects of Changing Atmospheric Trace Gases." 25 Reviews of Geophysics 1441-1482 (1987).

Ramanathan, V.; Cicerone, R.J.; Singh, H.B.; Kiehl, and Kiehl, J.T. "Trace Gas Trends and Their Potential Role in Climate Change." 90 Journal of Geophysical Research 5547-5566 (1985).



Reilly, John. "Climate Change Damage and the Trace Gas Index Issue." USDA, Economic Research Service (Draft November 1, 1990).

Rodhe, Henning. "A Comparison of the Contribution of Various Gases to the Greenhouse Effect." 248 Science 1217 (1990).

Shapiro, Michael & Warhit, Ellen, "Marketable Permits: The Case of Chlorofluorocarbons," 23 Nat. Res. J. 577 (1983).

Smith, Kirk R. and Ahuja, Dilip R. Toward a Greenhouse Equivalence Index: The Total Exposure Analogy. 17 Climatic Change 1-7 (1990).

Stavins, Robert N. "Harnessing Market Forces to Protect the Environment." 31 Environment 5 (January/February 1989) (summary of Project 88).

Stavins, Robert N., ed. Project 88 -- Round II. Draft Sept. 10, 1990.

Stewart, Richard B. "Controlling Environmental Risks Through Economic Incentives." 13 Colum. J. Envtl. L. 153 (1988).

Stewart, Richard B. "Current Experiments with Economic Instruments in Environmental Policy," paper presented at the EDF/AER\*X/USSR Academy of Sciences "Soviet-American Conference on Economic Instruments for Environmental Protection: From Theory to Practice," Washington D.C., November 12, 1990.

Stewart, Richard B. and Wiener, Jonathan B. "A Comprehensive Approach to Climate Change," 1 American Enterprise 75 (November-December 1990).

Stewart, Richard B. "Comprehensive and Market-Based Approaches to Global Change Policy," paper presented at the USDA/NOAA/Farm Foundation conference on "Global Change: Economic Issues in Agriculture, Forestry and Natural Resources," Washington D.C., Nov. 19, 1990.

Stewart, "Regulation, Innovation, and Administrative Law: A Conceptual Framework," 69 Cal. L. Rev. 1256 (1981).

Swisher, Joel N. and Gilbert M. Masters. "International Carbon Emission Offsets: A Tradeable Currency for Climate Protection Services." Stanford University (1989).

Tietenberg, Tom, Emissions Trading: An Exercise in Reforming Pollution Policy, RFF, Washington D.C., 1985.



Tripp, James T.B. and Daniel Dudek. "Comments of the Environmental Defense Fund on the IPCC Working Group III Economic Measures Paper." January 2, 1989.

Tripp, James T.B. and Daniel J. Dudek. "Institutional Guidelines for Designing Successful Transferable Rights Programs." 6 Yale J. Regulation 369 (1989).

U.S. Congressional Budget Office (D. Montgomery & R. Hitchner). "Carbon Charges as a Response to Global Warming: the Effects of Taxing Fossil Fuels," August 1990.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, "Atlantic Surf Clam and Ocean Quahog Fishery." 55 Fed. Reg. 24184 (June 14, 1990) (Final rule implementing Amendment 8 to the Fishery Management Plan) (to be codified at 50 C.F.R. part 652).

U.S. Interagency Task Force, "The Economics of Long-Term Global Climate Change: A Preliminary Assessment," Department of Energy, OPPA, DOE/PE-0096P, September 1990.

U.S. Environmental Protection Agency, "Certification Programs for Banking and Trading of Oxides of Nitrogen and Particulate Emissions Credits for Heavy-Duty Engines," 55 Fed. Reg. 30584 (July 26, 1990) (Final rule) (to be codified at 40 C.F.R. part 86).

U.S. Environmental Protection Agency, "Emission Trading Policy Statement," 51 Fed. Reg. 43,814 (1986).

U.S. Environmental Protection Agency, "Protection of Stratospheric Ozone," 53 Fed. Reg. 30,566 (1988) (to be codified at 40 C.F.R. pt. 82) (Final Rule) (capping CFC production with marketable permits); 53 Fed. Reg. 30,604 (1988) (Advance Notice of Proposed Rulemaking) (proposing allocation of permits).

U.S. Environmental Protection Agency, "Recommendation for Alternative Emission Reduction Options within State Implementation Plans," 44 Fed. Reg. 3,740 (1979) (proposed policy statement on "bubbles"), and 44 Fed. Reg. 71,780 (1979) (final policy statement); 40 C.F.R. 52.06 (1987) (codifying authority for state bubbles).

U.S. Paper on "Economic Measures" for the IPCC/OECD Seminar on Financial and Economic Measures As a Response to Climate Change, Paris, 26-27 April 1990.

U.S. Papers on "U.S. Experience with Comprehensive and Emissions Trading Approaches to Environmental Policy," Informal Seminar for IPCC WGIII officers, Washington, D.C., February 3, 1990.



Wigley, T.M.L.; Hulme, M.K; and Holt, T. "An Alternative Approach to Calculating Global Warming Potentials." Climatic Research Unit, University of East Anglia, Norwich, UK, Nov. 1990.