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THE WHITE HOUSE

WASHINGTON

March 16, 1990

Dear Mr. Okamatsu:

Thank you very much for sending papers on Japan's policy for preserving the global environment. I apologize that I was unable to meet with you during your recent visit, but I understand from Dr. Ratchford that you had a very useful meeting on global environmental problems.

I am looking forward to continuing cooperation on this very important subject.

Sincerely,

A handwritten signature in dark ink, appearing to read "D. Allan Bromley", with a stylized, flowing script.

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

Mr. Sozaburo Okamatsu
Director-General
Industrial Location and
Environmental Policy Bureau
Ministry of International
Trade and Industry
Japan

"INVITATION FOR DR. BROMLEY"

TYPE: Meeting only

DOCUMENT NUMBER: 9020897

SPEECH: YES NO

FROM: Sozaburo Okamatsu, Ministry of International Trade
and Industry - Japan

DATE OF EVENT:

LOCATION OF EVENT:

TIME OF EVENT:

SUBJECT: Meet with you during March on various matters
concerning the global environment.

RSVP: 03/16/90

CONTACT PERSON: Sarah Bowden

CONTACT NUMBER: OSTP

INVITATION ACCEPTED? YES NO

COPIES TO: Sara Bowden
Thomas Ratchford
James Wyngaarden

REMARKS: Received from Sara R. Bowden - asked us to track and
return copy to her for processing - sent Wyngaarden copy
for Nancy Maynard because of topic of Global Environment.

DATE OF LETTER: 02/22/90

DATE RECEIVED: 03/07/90

FILE: NEOB

"CORRESPONDENCE TRACKING"

TYPE: Information

DOCUMENT NUMBER: 9020906

FROM: Sozaburo Okamatsu, Ministry of International Trade and Industry -
Japan

TO: Bromley

DATE OF
CORRESPONDENCE: 03/07/90

SUBJECT: Enclosing materials related to Japan policy
consideration to combat global warming. Xref
#9020897 (invitation for meeting on such) #9020041
(cover sheets attached)

ASSIGNED TO: NOT ASSIGNED TO ANYONE

ACTION REQUIRED:

SENDER'S DUE DATE:

OSTP DUE DATE:

DATE COMPLETED:

COPIES TO: Thomas Ratchford
Sara Bowden
James Wyngaarden

WHITE HOUSE TRACKING #:

CONTACT PERSON:

REMARKS:

DATE RECEIVED: 03/09/90

FILE: NEOB

THE WHITE HOUSE
WASHINGTON

Hed

March 20, 1990

MEMORANDUM FOR THE DPC WORKING GROUP ON GLOBAL CHANGE

FROM: D. ALLAN BROMLEY *Dna*
SUBJECT: Task Force on Economic Costs Report

Enclosed herewith is the preliminary draft of the above mentioned task force report.

I have already expressed to Richard Schmalensee and his group my appreciation of the excellent work that this report reflects. I know that he, and they, will welcome any comments or suggestions that you may have concerning it and would encourage you to communicate them directly to Dr. Schmalensee.

We will have an opportunity to discuss this report in a Working Group meeting in the near future.

Please do not copy or otherwise distribute this preliminary draft.

Attachment

5



COUNCIL OF ECONOMIC ADVISERS
EXECUTIVE OFFICE OF THE PRESIDENT
WASHINGTON

MEMBER OF THE COUNCIL

March 5, 1990

MEMORANDUM FOR THE HONORABLE D. ALLAN BROMLEY
ASSISTANT TO THE PRESIDENT FOR
SCIENCE AND TECHNOLOGY AND DIRECTOR
OFFICE OF SCIENCE AND TECHNOLOGY POLICY

FROM: RICHARD SCHMALENSEE

SUBJECT: Enclosed report

I hereby submit to you and thus to the DPC Global Change Working Group the enclosed report of the Task Force on Economic Cost. (I have also sent copies to all Task Force members, including Nancy Maynard, and to a few interested individuals in the complex.) The "Preliminary Draft" header is intended as leak protection; no further work is planned.

CEA is mainly responsible for the lateness of this report; we were slowed by the Economic Report of the President and by severe secretarial and word processing problems. All other agency representatives on the Task Force discharged their responsibilities well and quickly and deserve the Working Group's thanks. I strongly believe that this consensus document is a better report than any single agency could have produced and that it describes well what we know and don't know. I would be happy to sketch its findings to the DPC Working Group if you think it appropriate, though it may be more efficient simply to direct Working Group members to the Executive Summary.

I await your decision regarding the distribution and/or presentation of this document.

Attachment
Global Climate Report

OFFICE OF THE
DIRECTOR

90 MAR 6 P 2: 41

RECEIVED

PRELIMINARY DRAFT

OFFICIAL USE ONLY

**THE ECONOMICS OF GLOBAL CLIMATE CHANGE:
A PRELIMINARY ASSESSMENT**

**Task Force on Economic Costs
Working Group on Global Change
Domestic Policy Council**

Version of March 1, 1990

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EXECUTIVE SUMMARY

There are substantial gaps in current knowledge about the economics and physical science of global climate change. In fact, almost all the quantitative projections in this report, as well as many of the qualitative assertions, are controversial. Projections of climate effects and costs in the distant future are inherently less reliable than forecasts of climate and policy costs in the short run.

The Task Force recommends that an interagency, coordinated economic research program be undertaken, similar to that in the climate sciences, that would evaluate the economic effects of possible future climate change and the benefits of slowing such change, the costs and effectiveness of various adaptive and emissions reduction measures, and the effects of such measures on U.S. and world trade and capital flows.

The remainder of this Executive Summary provides a very brief outline of our main findings. Readers with an interest in a particular topic, such as the impact of possible climate change on agriculture or estimates of the economy-wide impacts of measures to limit carbon dioxide emissions, should note that the main report, while lengthy, is structured to allow for a selective reading.

BACKGROUND

Greenhouse Gas Emissions

Possible climate change is not a one-gas or one-nation problem. Carbon dioxide, CFCs, methane, and nitrous oxide have accounted for about 87 percent of the increase in radiative (greenhouse) forcing in the 1980s. Projections of future emissions of these gases are uncertain, and comparisons of the effects of those emissions are not completely straightforward.

Carbon Dioxide: Given the projected expansion in fossil energy use throughout the world, CO₂ is expected to account for a larger share of increased radiative forcing in the future than in the past. The United States now accounts for about 21 percent of total anthropogenic CO₂ emissions, but that share is expected to shrink to around 12 percent by the middle of the next century.

Methane: Emissions rates of major sources of CH₄ are subject to significant uncertainty. Over half of total anthropogenic emissions of methane are produced by domestic animals (enteric fermentation) and rice cultivation. Centrally-planned and developing nations account for the bulk of these emissions.

CFCs: The United States and other developed nations now account for well over half of emissions of CFCs and related gases, but the shares of developing nations are expected to increase sharply as reductions and phaseouts are implemented in accord with the Montreal Protocol.

Nitrous Oxide: Most N₂O emissions are associated with agricultural activity and animal husbandry. Data on natural and anthropogenic sources of nitrous oxide emissions are poor.

Potential Climate Changes

Projections of future emissions of greenhouse gases are highly sensitive to future rates of population growth, economic growth, and development of new technologies for energy production and use. The inability to place narrow bounds on any of these factors necessarily places very wide bounds on any forecast of future emissions.

Even if future emissions are assumed to be known, considerable uncertainty attaches to the climate changes that would result from increased atmospheric concentration of greenhouse gases. The effects of greenhouse gases on global climate are forecast by climate models, a relatively new tool, that may be reliable for the direction of temperature change but not for its extent. Climate models predict that a doubling of the concentration of carbon

dioxide relative to the preindustrial atmosphere--or its equivalent in terms of a combination of greenhouse gases--would result in an eventual global average warming of between 2 and 9 degrees Fahrenheit. If the atmosphere begins to warm, a transfer of heat from the air to the oceans is expected to slow the rate at which air temperature actually rises. This effect could delay the full impact of any given increase in the concentration of greenhouse gases on observed air temperature for decades or even centuries, with wide variations by region.

Some models suggest a marked soil moisture decrease in mid-latitude continental regions during summer. Global sea-level increases by 2050 of 25 to 40 centimeters (recent IPCC estimate) could occur if warming of 2° to 9° Fahrenheit occurred by the middle of the next century. Regional impacts of possible climate change are highly uncertain.

Policy Alternatives

Planned adaptation involves actions taken in recognition of anticipated warming to deal with its effects. Unplanned adaptation involves short-run responses to actual warming as it takes place. Mitigation policies are aimed at reducing the rate of possible warming by reducing net emissions of greenhouse gases. Mitigation policies must generally be implemented well before adaptation policies. They must also be implemented on a global scale. The important economic implications of differences in timing between adaptation and mitigation costs can only be revealed by discounting.

Given that the risk of global warming is still unclear, additional research is certainly called for. Beyond that, relatively inexpensive, flexible policies that can easily be reversed or expanded, and policies that can be justified for reasons other than climate change should be highly valued.

ADAPTATION: LIVING WITH GLOBAL WARMING

Climate and the Economy

The direct economic effects of climate change would be concentrated primarily in agriculture, forestry, and possibly fisheries, which currently account for about 2 percent of U.S. Gross Domestic Product (GDP) and about 5 percent of world GDP. In addition, a rise in the sea level could inundate valuable dry land. Apart from agriculture and sea-level rise, little quantitative research on climate impacts or adaptation costs has been done.

The indirect effects of climate change will create winners and losers throughout the United States and global economies as demand shifts occur. For example, demand for air conditioners and summertime electricity could rise, while demand for space heating equipment and fuels and could fall. Tourism might also be affected. The costs of adaptation would depend critically on how rapidly warming occurs relative to the economic lifetimes of major immobile assets.

Agriculture

Climate change could affect agricultural yields both positively and negatively through variations in regional temperature, seasonality, precipitation, and soil moisture. Estimates of these effects are very uncertain. While increased CO₂ concentrations alone would likely have a direct positive effect on efficiency of photosynthesis and water use, the effects of higher temperatures could reduce yields. Estimates of the impact of future global change on U.S. cereal crop yields range from an increase of 10 to 15 percent to a decrease of about the same magnitude.

Net economic effects on any country's agricultural sector depend on global yields and consequent impacts on market prices and trade flows as well as on regional yield effects. USDA analysis shows that a scenario involving U.S. yield decreases of between 10 and 15 percent results in slightly

increased overall U.S. welfare once the effects of increased export prices are factored into the analysis. This analysis suggests that climate-induced changes in agriculture would not produce major positive or negative economic effects by the middle of the next century. Yet, there could be significant regional dislocations in crop production.

Sea-Level Changes

The adverse effects of possible sea-level rise on coastal infrastructure, recreation, and coastal ecology could be either large or small, depending on the rate and magnitude of any sea-level rise and on the extent of planned adaptation. While densely developed shoreline areas in the United States could be protected against sea-level rises that might occur by 2050 for less than \$10 billion (present value), significant net losses of drylands and wetlands could occur.

Human Health

The impacts of a possible warming on human health are extremely controversial, and the scope for planned adaptation is unclear. Some studies show significant possible increases in heat-related deaths, while others argue that cities with appreciably different climates show no climate-related differences in health risk. Global warming would likely cause some vector-borne tropical diseases to spread northward, but the magnitude of this problem is unclear. On the other hand, there could be a decline in cold-related deaths.

Other Potential Effects

Forestry: If significant warming occurs, changes in U.S. forests could be apparent in 30 to 80 years. Significant changes in forest range are possible. Changes in forest distribution and composition could have major impacts on timber production, runoff from forests, and recreational opportunities. Without human intervention, rapid warming may make a northward

forest migration difficult. Today's forest management decisions could have long-term impacts on the composition and location of forests.

Fisheries: Fishery resources are known to be sensitive to climate variation. However, the qualitative effects of warming on fisheries are highly uncertain, and no quantitative economic analysis has, to our knowledge, been attempted. Absent human intervention, ocean species are likely to be less affected by any climate change than freshwater species, since oceans would respond to atmospheric warming more slowly than smaller bodies of water. Both the need and the opportunity for planned adaptation in the commercial fishing sector appears to be limited.

Water Resources: In general, it is difficult to predict the impacts of climate change on water resources with much confidence because of uncertainties about regional precipitation. If significantly higher temperatures occur, water supplies in California and the lower Great Lakes could be reduced.

Biodiversity: The impacts of climate change on natural communities are difficult to predict. Possible global warming could result in a decline in biodiversity stemming from the loss or change of habitats that result in the decline or loss of some animal and plant species.

MITIGATION: LIMITING GREENHOUSE GAS EMISSIONS

The costs of reducing carbon dioxide and CFC emissions are under active study. Available estimates of CO₂ abatement costs remain preliminary and controversial. Relatively little is known about the costs of reducing emissions of other greenhouse gases. A revision of this section of the report a year or two from now could rely on a much stronger research base (particularly as regards CO₂) and might well have different policy implications.

Background

Global Action & Differential Impacts: Global action is essential if meaningful reductions in the expected growth of any of the greenhouse gases are to be obtained without bringing economic growth to a halt. Even dramatic unilateral cuts by the OECD member states would not be sufficient to achieve widely-discussed global CO₂ goals unless most other countries participate fully in emissions reduction efforts. For example, even the total elimination of OECD emissions over the next 15 years would be insufficient to obtain a 20 percent global emissions reduction by 2005 if the USSR and Eastern Europe only stabilize emissions at their current levels and developing countries take no action to curb CO₂ emissions growth. Global action would also be necessary to control methane and nitrous oxide emissions, which result primarily from agricultural activities.

Differences in costs and benefits among nations may make it difficult to obtain global agreement on specific goals and policies. For example, countries that rely heavily on coal, which contains a relatively high amount of carbon per unit of energy, may have greater concerns than other nations regarding the impact of restrictions on CO₂ emissions on their level of oil and gas imports and the consequent implications for energy security and trade balances.

Incentives and Market Failures: An approach to limiting net anthropogenic greenhouse emissions that encompasses all important greenhouse gases and gas sinks as well as gas sources is preferable to one that considers each source of greenhouse gases individually. Also, any set of nations should be free to develop a joint strategy to meet their pooled ceilings, as long as net global emissions are not thereby increased and existing treaty obligations are not thereby violated. An approach incorporating these elements was outlined in a U.S. concept paper tabled at the IPCC.

All analysts agree that some reductions in greenhouse gas emissions can be obtained at low cost. Reductions in CFCs under the current provisions of

the Montreal Protocol and the CFC phaseout likely to be included in a revised Protocol this year fall into this category. There is disagreement as to the extent of low-cost opportunities for limiting other greenhouse gases, but some such opportunities undoubtedly exist.

Administration regulatory policy generally holds that primary reliance should be on incentive-based approaches--including charges, user fees, and tradable emissions rights. When market failures limit the power of such approaches, those failures can be addressed directly. Command-and-control efficiency standards have several significant disadvantages in comparison to incentive-based systems or approaches that address perceived market failures directly. The costs of efficiency standards are often hidden rather than explicit.

Carbon Dioxide

Economy-Wide Analyses of Emission Limitation Costs: Several studies of carbon dioxide reduction costs using economy-wide models have recently been completed or are now in progress. Existing papers (and work in progress that we have been briefed on) use a variety of modeling approaches, consider different policies, and employ different baseline emissions growth assumptions. These differences have important effects on cost estimates. All results should be considered preliminary.

In general, work to date finds that the costs of stabilization or reduction of CO₂ emissions by 2005 will be high--at least 1 percent of GNP per year for widely discussed objectives, such as stabilizing CO₂ emissions at the present level or securing and maintaining a 20 percent reduction from that level. Some estimates suggest that achievement of such objectives would involve significant reductions in long-term growth. The experience of the U.S. economy in the 1973-85 oil shock period, when CO₂ emissions were constant but economic growth was slow, offers a useful reference for comparison of likely impacts of policies to sharply curtail fossil energy use on output and productivity growth.

Some recent analyses consider the use of a charge on the carbon content of fossil fuels to reduce CO₂ emissions. This research generally concludes that charges on the order of \$100 per ton (which would amount to roughly a 180 percent increase in the delivered price of coal and a 70 percent increase in the price of oil) would be needed to have a significant effect on emissions. Much lower carbon charges may be of some value in the near term to compensate for known external effects of energy use, to test the sensitivity of CO₂ emissions to incentives, and to lay the foundations for higher future charges if they are found necessary.

The aggregate economic effects of CO₂ emissions reduction policies would not be felt evenly throughout the U.S. economy. The relative cost of energy would increase substantially, increasing the relative price and decreasing the consumption of energy intensive products. It is impossible to construct a scenario for substantial CO₂ emissions reduction without a major adverse impact on the coal industry. General equilibrium modeling suggests that an effort to significantly limit CO₂ emissions would cause large changes in the sectoral composition of the U.S. economy. Such sectoral changes, if gradual, might occur without a drastic impact on the value of existing assets. However, a policy that resulted in rapid sectoral changes could have a significant impact on the value of assets in impacted industries and on the value of immobile assets, such as residential housing, in impacted communities.

Because the United States relies heavily on coal, the fossil fuel with the highest amount of carbon per unit of energy, for electricity generation, U.S. electricity rates would be likely to rise more than those in other industrialized countries if concerted action were taken to curb CO₂ emissions. Unless energy-intensive U.S. industries were able to greatly increase their energy efficiency, they could be disadvantaged relative to major foreign competitors who would be less affected by electricity rate increases.

Regulatory Adjustments: There are a number of reasons why total U.S. investment in energy-efficiency may be suboptimal. Many analysts have called

for a variety of regulatory initiatives to increase the efficiency of energy use and, thereby, to reduce CO₂ emissions.

The elimination of electricity pricing distortions would be as likely to yield increases in consumption and emissions as decreases. Many analysts have called for reform of electric and gas utility regulation to give utilities incentives to remove impediments to efficient investment in energy conservation. While the desirability of regulatory changes of these sorts is apparent, estimates of potential reductions in CO₂ emissions vary widely.

Energy-efficiency standards for buildings, appliances, and automobiles represent another approach to limiting energy consumption, and thus CO₂ emissions. However, Administration regulatory philosophy generally favors addressing any information problems, institutional rigidities, or market failures that may exist directly, rather than attempting to compensate for them via efficiency standards that can impose significant hidden costs on consumers and the economy at large.

A number of changes in agricultural programs that would have other benefits can be expected to assist reducing greenhouse gas emissions. These include reducing commodity price support levels, encouraging additional tree planting, and conservation programs.

New Technologies: While new technologies offer significant CO₂ emissions reduction potential after 2000, there is no simple "technological fix" to this problem. A variety of technologies for generating electricity are in various stages of development. The next generation of nuclear reactors, based on simplified and standardized designs and passive safety features, may come into use after 2000. Advanced energy use technology seems to have the potential to contribute significantly to reducing CO₂ emissions, but estimates of the extent of the contribution vary widely.

Increases in DOE's R&D budgets for end-user energy efficiency improvements and for DOE programs that provide financial and technical assistance to states, both of which have declined in recent years, would

enhance conservation efforts. Most studies have found that the potential gains from widespread use of available "best practice" technology are significant, possibly up to 15 percent of current consumption.

Forestation: Reforestation is a (comparatively) short-term approach that could generate a substantial decrease in net CO₂ emissions for at least three to five decades. Cost estimates in one study of a global strategy ranged from \$4.29 to \$8.03 per metric ton of carbon removed, while those in another study for the United States ranged from \$17.71 to \$102.63 per metric ton depending on program size. The net ecological and recreational benefits of forestation would depend on the type of forest planted and the current use of the land. The efficacy of forestation as a carbon management tool depends importantly on how the stock of accumulated carbon in mature forests is managed, but the costs and carbon removal potential of alternative management strategies have not been systematically analyzed.

Methane

Because the developed countries account for only about 25 percent of anthropogenic methane emissions, significant, cost-effective reductions in CH₄ emissions will require global action. Feasible reductions in the areas of animal waste, sizes of livestock herds, coal mining, landfills, and livestock and rice production add up to more than enough to stabilize atmospheric CH₄ concentrations. While a number of approaches to controlling these emissions are available, no systematic policy design or costing analysis has been performed.

Chlorofluorocarbons (CFCs)

The Montreal Protocol, which calls for a reduction in CFC emissions has been ratified by nations that account for over 90 percent of global consumption. The Protocol will be renegotiated in June 1990 and will almost certainly include a phaseout of all CFCs by 2000 for applications where safe substitutes are available. With widespread participation, this phaseout would

significantly reduce the increase in radiative forcing attributable to greenhouse gas emissions during the next century. The costs of eliminating the use of CFCs will be approximately \$3 billion (present value) over the next 10 years.

Nitrous Oxide

No systematic attention seems to have been devoted to the design or cost of policies to reduce N₂O emissions from fertilizer use or other sources, in part because the relevant science base is weak.

I. INTRODUCTION

The charge of this Task Force was stated in a memorandum of October 23, 1989, from Allan Bromley to Michael Boskin as follows:

As you know, rational models of the economic cost of either action or inaction, are conspicuously missing from the public and international debate on the subject. Economic consequences must be understood before sound policy can be developed and economically and socially acceptable actions taken. We simply cannot proceed without that understanding.

I would ask that your Task Force on Economics include broad interagency representation and identify, review, and inventory similar work being done elsewhere--at universities, think-tanks, and by your counterparts in other industrialized nations. I would ask you to produce at least a preliminary report in three months.

The members of this Task Force, who are listed at the end of this report, were encouraged to draw on the full range of resources within their agencies. The Bibliography at the end of this document provides a fairly complete but not exhaustive inventory of work that bears on the economics of global change. It draws on a wide range of sources. (In particular, unpublished economic studies that have been reviewed by CEA were included.)

Task Force members agreed on the outline of this report and took responsibility for first drafts of individual sections. Drafts of the report were prepared by CEA on the basis of agency submissions and were reviewed by the Task Force.

Because this report was prepared with tight deadlines, it necessarily embodies very little new research. It is intended to provide an overview of current knowledge and key facts. It should serve to indicate that economic analysis of global change is in its infancy; few assertions about costs or benefits can be made with confidence. The state of the literature, the diversity of views on the Task Force, and our schedule combine to preclude any attempt to produce anything like a comprehensive benefit-cost analysis. (But

see Nordhaus (1989) for a crude but interesting attempt.) Moreover, almost all of quantitative estimates in this report, as well as many of the qualitative assertions, are controversial.

Section II provides background on greenhouse gas emissions and their likely climatic effects and on available policy types. Section III considers the costs of living with global change, assuming no substantial efforts to reduce greenhouse gas emissions. Section IV considers costs of reducing those emissions. The individual Sections are not entirely compartmentalized, but can be read independently if necessary.

II. BACKGROUND

This section provides background material on current and projected future greenhouse emissions and on scientific opinion regarding the effects of those emissions on the global climate. The final subsection provides a brief, general discussion of adaptation and mitigation strategies to serve as an introduction to the analysis of these strategies in Sections III and IV, respectively.

A. Greenhouse Gas Emissions

Increases in the atmospheric concentrations of at least 25 trace gases contribute directly or (via chemical reactions) indirectly to the retention of solar radiation by the earth (radiative forcing). Five greenhouse gases, described in Table II.1, have accounted for about 87 percent of the increase in radiative forcing in the 1980s and about 92 percent of the increase over the 1880-1980 period (Ramanathan, et al., 1985; Hansen, et al., 1988). These gases are, accordingly, the focus of the rest of this subsection and of the mitigation strategies considered in Section IV. The emissions projections for these gases in Tables II.2-5 are based on the Rapidly Changing World scenario

in Lashof and Tirpak (1989); they should be treated as providing rough orders of magnitude, not precise estimates.

Table II.1
Main Greenhouse Gases

Gas	Percentage Share		
	of Increased Radiative Forcing in the 1980s	Atmospheric Lifetime (years)	Forcing Index (molecular)
Carbon Dioxide (CO ₂)	49	250	1
Methane (CH ₄)	19	10	30
Chlorofluorocarbons (CFC-11 & CFC-12)	14	60 & 75	22,000 & 25,000
Nitrous Oxide (N ₂ O)	5	100-175	200

Sources: Hansen, et al. (1988); Department of Energy; Wuebbles and Edmonds (1988).

Comparisons of the effects of future emissions of various greenhouse gases are not completely straightforward. Differences in atmospheric lifetimes lead to different time patterns of effects, so that decisions regarding discounting may be important (Lashof and Ahuja, 1989). (Note also the uncertainty attached to the lifetime of N₂O.) And, while the radiative forcing effects of changes in atmospheric concentrations of any trace gas are apparently easy to calculate, the effects of changes in emissions on atmospheric concentrations depend both on pre-existing concentrations and on various imperfectly understood geophysical feedbacks, which also affect atmospheric lifetimes.

1. Carbon Dioxide. Measurements of CO₂ levels show atmospheric concentrations increasing from somewhere between 250 and 295 parts per million (ppm) at the beginning of the 19th century to 346 ppm in 1986. Good data are

available on fossil fuel CO₂ emissions and (the far smaller) emissions from cement production; data on the impacts of land use changes (primarily tropical deforestation) are fair to poor. It is important to keep in mind that natural flows of carbon into and out of the atmosphere are roughly ten to twenty times larger than the (anthropogenic) flows associated with human activity.

Table II.2 provides historic and projected anthropogenic emissions data by region and by source assuming no mitigation. These projections are uncertain because of uncertainties about future population and economic growth, sectoral composition of GNP, and sector-specific energy efficiencies. Nonetheless, it is important to note that because energy-related sources of CO₂ emissions are expected to grow comparatively rapidly, and CFCs are expected to be controlled significantly, CO₂ is expected to account for a larger share of increased radiative forcing in the future than in the past.

Table II.2
Carbon Dioxide Anthropogenic Emissions Share Projections

Source	Percentage Shares			
	1985	2000	2015	2050
<u>Countries</u>				
United States	21	19	16	12
Rest of OECD	22	19	16	12
USSR & Eastern Europe	22	22	19	18
Centrally Planned Asia	10	13	16	21
Other Developing	<u>25</u>	<u>28</u>	<u>32</u>	<u>37</u>
	100	100	100	100
<u>Sectors</u>				
Commercial Energy	86	87	89	92
Tropical Deforestation	12	11	9	6
Other	<u>2</u>	<u>2</u>	<u>2</u>	<u>2</u>
	100	100	100	100
Total Scenario Emissions (10 ⁹ tonnes Carbon)	5.99	8.05	10.27	16.95
Average Annual Growth Rate	1.6%			

Source: USEPA (1989) Rapidly Changing World Scenario

The U.S. now accounts for about 21 percent of total anthropogenic CO₂ emissions, but that share is expected to shrink to around 12 percent by the middle of the next century. Despite the attention paid to tropical deforestation, most anthropogenic CO₂ emissions are and will be the result of combustion of fossil fuels. The United States has comparatively high CO₂ emissions per capita from fossil fuel consumption and cement production, in part because it makes relatively heavy use of coal. In the United States, coal burned by electric utilities accounts for 31 percent of total fossil fuel CO₂ emissions; the entire utility sector accounts for 37 percent, and the transportation and industrial sectors account for 29 and 21 percent, respectively.

2. Methane. Atmospheric concentrations of CH_4 were relatively constant prior to the middle of the last century at about 700 parts per billion (ppb); by 1987 CH_4 concentrations had increased to 1675 ppb. Recently, atmospheric concentrations of methane have been increasing at an observed rate of about 1.1 percent annually. The contributions of the different sources of methane that together account for aggregate emissions remain uncertain. Anthropogenic emissions of CH_4 are thought to account for roughly two-thirds of all emissions. Table II.3 contains estimates of anthropogenic emissions; they should be treated as uncertain.

The United States now contributes about 12 percent of anthropogenic emissions of CH_4 ; this share is predicted to decline to about 8 percent. Over half of total anthropogenic emissions of methane are produced by domestic animals (enteric fermentation) and rice cultivation. The centrally-planned and developing nations account for the bulk of these methane emissions. Energy-related methane emissions occur in coal mining, and when natural gas is gathered, transmitted, distributed or vented.

Table II.3
Methane Anthropogenic Emissions Share Projections

Source	Percentage Shares			
	1985	2000	2015	2050
<u>Countries</u>				
United States	12	11	9	8
Rest of OECD	13	12	12	10
USSR & Eastern Europe	13	14	14	15
Centrally Planned Asia	17	16	17	19
Other Developing	<u>46</u>	<u>47</u>	<u>49</u>	<u>48</u>
	100	100	100	100
<u>Sectors</u>				
Fuel Production	18	22	26	32
Enteric Fermentation	23	24	23	22
Rice Cultivation	34	31	29	24
Landfills	9	10	10	14
Tropical Deforestation	6	6	5	4
Other	<u>9</u>	<u>7</u>	<u>7</u>	<u>5</u>
	100	100	100	100
Total Scenario Emissions (10 ⁶ tonnes CH ₄)	320.1	399.5	476.8	710.5
Average Annual Growth Rate			1.2%	

Source: USEPA (1989) Rapidly Changing World Scenario

3. Chlorofluorocarbons. CFCs are entirely man-made and were discovered during the 20th century. The concentrations of CFC-11 and CFC-12 were 226 parts per trillion (ppt) and 392 ppt, respectively, in 1986 and have been rising at 4 percent annually. Table II.4 gives projected regional emissions of these two gases assuming implementation of the Montreal Protocol (aimed at reducing stratospheric ozone depletion) in its present form, with 100 percent participation by developed countries and 75 percent participation elsewhere. (As Section IV.D. notes, it is likely that the Protocol will be

revised to call for a phaseout of CFCs by the year 2000 for applications where there are safe substitutes.)

Table II.4

Chlorofluorocarbon (CFC-11 + CFC-12) Emissions Share Projections
Assuming no Further Controls Beyond Present Montreal Protocol

Source	Percentage Shares			
	1985	2000	2015	2050
United States	24	18	17	12
Other Developed	41	24	24	21
USSR & Eastern Europe	16	14	14	13
0.2Kg Nations*	6	14	15	19
Other Developing	<u>12</u>	<u>30</u>	<u>30</u>	<u>36</u>
	100	100	100	100
Total Scenario Emissions (10 ³ tonnes CFC)	642.1	837.8	755.1	828.5
Average Annual Growth Rate	0.4%			

* Nations with CFC use between 0.1 and 0.2 kilograms per capita and likely to reach the 0.3 kilogram per capita limit in the Montreal Protocol prior to 1999.

Source: USEPA

Note that global emissions of CFC-11 and CFC-12 are projected to increase under the present terms of the Montreal Protocol. Emissions of related greenhouse gases (particularly CFC-22 and Methyl Chloroform) are projected to increase quite rapidly. Considering these related gases does not alter the message of Table II.4: the United States and other developed nations now account for well over half of emissions of CFCs and related gases, but, with no further controls beyond the present Montreal Protocol, the shares of developing nations are expected to increase sharply. The speed with which safe substitutes are identified and the extent of developing country participation in the likely phaseout of CFCs are uncertain and will significantly affect future shares and quantities of emissions.

4. Nitrous Oxide. Atmospheric concentrations of N_2O averaged about 285 ppb from 1600 to 1800, began to rise slowly at the start of this century and more rapidly after 1940, and are now around 310 ppb. Data on natural and anthropogenic sources of N_2O emissions are poor, and the data in Table II.5 should be considered as approximate at best. The Department of Energy believes that N_2O emissions associated with energy processes may be overestimated by an order of magnitude.

Table II.5
Nitrous Oxide Anthropogenic Emissions Share Projections

Source	Percentage Shares			
	1985	2000	2015	2050
<u>Countries</u>				
United States	14	12	11	9
Rest of OECD	13	14	14	12
USSR & Eastern Europe	14	15	14	13
Centrally Planned Asia	13	16	14	15
Other Developing	<u>46</u>	<u>47</u>	<u>47</u>	<u>52</u>
	100	100	100	100
<u>Sectors</u>				
Coal Combustion	25	26	29	36
Fertilizer Use	38	43	44	41
Gain of Cultivated Land	10	8	8	6
Tropical Deforestation	13	11	10	9
Fuelwood & Ind. Biomass	5	4	3	2
Agricultural Wastes	<u>10</u>	<u>8</u>	<u>7</u>	<u>6</u>
	100	100	100	100
Total Scenario Emissions (10^6 tonnes N_2O)	4.21	5.85	6.87	8.85
Average Annual Growth Rate			1.2%	

Source: USEPA

As in the case of methane, most N₂O emissions are associated with agricultural activity and with developing nations. Increased fertilizer use has both raised N₂O emissions and dramatically increased food supplies in many developing nations. The U.S. share of world N₂O emissions is only about 14 percent and is expected to fall below 10 percent by mid-century.

B. Potential Climate Changes

Formulating a realistic and responsible outlook on possible climate effects associated with increasing atmospheric greenhouse gas concentrations requires providing answers to a sequence of increasingly complex questions.

1. Uncertainties. It is first necessary to project future emissions of greenhouse gases. As noted above, such projections are inevitably uncertain. It is then necessary to predict how much of the assumed emissions will remain in the atmosphere after accounting for the effects of natural processes. Typical tentative scenarios, like those underlying the emission share projections in tables II.2 to II.5, assume that emissions will be sufficient to result in the radiative equivalent of a doubling of atmospheric carbon dioxide (the combined effects of CO₂ and other trace gas increases) between 2030 and 2070.

Once the greenhouse gas levels in the atmosphere are projected, the next step is to project associated changes in heating of the earth system as a whole. An increase in radiative forcing by greenhouse gases does not necessarily imply a significant warming of the planet. For instance, it has been argued that a strong negative cloud feedback mechanism could counter the effects of greenhouse gas buildup. In this case little net warming of the system would take place. A recent study found that using a different representation of clouds in a climate model reduces the predicted global warming by a factor of two to three. However, scientists have identified other possible feedback mechanisms that would make the warming problem worse than predicted. The best climate models available today indicate that

increased greenhouse gas concentrations will lead to some warming of the overall earth system. Because potentially important positive and negative feedbacks which have not been adequately modeled are known to exist, the questions of whether a systematic warming will take place, and its magnitude, must still be considered as open.

The next question is more subtle and complex: to what extent will a warming of the earth system be manifested in actual surface temperature change? The role of the ocean as a heat sink illustrates this issue well. Recent computations with one of the world's leading coupled ocean/atmosphere models indicate that a one percent per year carbon dioxide buildup (doubling by 2040; redoubling by 2120) would produce for the Northern hemisphere a warming of 3.8°F at the equator by 2050, increasing to around 7.2°F at high latitudes. But in this computation, the Southern latitudes hardly warm at all because the high latitude southern ocean absorbs virtually all the heat from greenhouse warming (ocean temperatures increase slightly). Under this model, the earth system would clearly warm, but air temperatures would scarcely be affected in the Southern Hemisphere. The particular configuration of the ocean, atmosphere and land surface in the Southern Hemisphere is responsible for this outcome. More generally, observed increases in air temperatures will lag behind equilibrium temperature increases (those that would eventually occur with given atmospheric concentrations of greenhouse gases) for decades or even centuries.

While considerable advances have been made in climate models, it is important to note that model simulations of global warming are not consistent with the historical record, itself the subject of considerable debate. The available models predict an increase in global surface temperature with increasing greenhouse gases, but analyses of land and sea surface temperature changes over the past century generally fail to detect such a pattern. On the other hand, our ignorance is a two-edged sword. Some scientists view increased risk of catastrophic climate changes--such as a sudden shift in the ocean currents that now warm Western Europe--that might be produced by

geophysical processes we do not understand well as a major adverse consequence of increasing atmospheric concentrations of greenhouse gases.

2. Projections. Because of these multiple, compounding uncertainties, quantitative model projections of greenhouse gas warming must be considered speculative and subject to improvement as understanding progresses. All climate models predict that doubling the concentration of CO₂ relative to the preindustrial atmosphere would result in an eventual global average warming. The quantitative predictions for actual (realized) average warming by 2050 vary over the range 2°F-8°F. (The low (high) end of this range corresponds roughly to the annual average difference between Washington and Sacramento (Dallas).) However, some recent results from models using specifications of cloud behavior believed to be more realistic have reduced equilibrium warming projections by half. Modelers generally agree that seasonality will decrease, with winter temperatures rising more than summer ones.

The models differ substantially on regional scale projections, compounding an already difficult problem of predicting regional temperature, precipitation or soil moisture. There is general agreement among climate modelers that, while precipitation would increase globally in a global warming scenario, regional patterns of precipitation would probably change, leaving some areas considerably wetter or drier. Translating these precipitation changes into changes in soil moisture is yet another question, since soil moisture is a function of soil and vegetation characteristics as well as precipitation, temperature, and humidity. Differences in soil moisture and temperature could also affect soil's capacity to absorb greenhouse gases. Some models suggest a marked soil moisture decrease in midlatitude continental regions during summer.

Possible changes in worldwide sea level are also subject to extreme uncertainty. Warming could raise sea level by thermal expansion of the upper layers of the ocean and by the melting of land-based ice. However, current

measurements have found that Greenland and Antarctic ice cover is currently increasing, not melting away. An American Geophysical Union panel recently suggested a range of global sea-level increases by 2050 of between 10 and 70 centimeters. The science group of the Intergovernmental Panel on Climate Change (IPCC) is apparently reaching consensus that a warming within the range projected by climate models might be accompanied by a global sea-level rise of between 25 and 40 centimeters by 2050.

C. Policy Alternatives

The next two sections of this report consider the two basic types of policies available to deal with global change: adaptation and mitigation.

Adaptation policies, which seek to lower the costs of global warming, come in two forms: planned and unplanned. Planned adaptation involves actions taken in advance of anticipated warming; examples include development of heat-resistant plant strains and decisions not to undertake new construction on land that may be inundated by sea-level rise. Unplanned adaptation involves reactions to actual warming, such as the use of more air conditioning. For the most part, effective planned adaptation policies can be designed and implemented at the local or national levels, while unplanned adaptation mainly reflects decisions of individual firms and households. If global warming occurs over time, adaptation would also be a continuing process.

Mitigation policies are aimed at reducing net emissions of greenhouse gases. This can be done either by reducing gross emissions (by reducing the use of CFCs or the burning of fossil fuels, for instance) or by increasing the removal of greenhouse gases from the atmosphere by natural processes (by reforestation, for instance).

Because some greenhouse gases have long atmospheric lifetimes, and because any changes in climate may lag changes in net emissions by many decades, mitigation policies must generally be implemented well before adaptation policies. Using a 5-percent real discount rate, \$100 billion spent

on adaptation in 2050 is equivalent in terms of cost to \$4.2 billion spent on mitigation today. (If an investment yields a 9-percent rate of interest in dollar terms, but prices rise at 4 percent per year, the real purchasing power of invested funds grows by 5 percent annually.) A 5-percent real discount rate is used throughout this report, but the literature contains arguments for both higher and lower rates.) Because the time scales here are longer than in most issues, the important economic implications of differences in timing between adaptation and mitigation can only be revealed by discounting.

Effective policy design must reflect the fact that there are great uncertainties about future emissions, implied climate changes and their effects, and the costs of reducing net emissions. It is of course important to support scientific and economic research to close the many gaps in our knowledge. But it is also important to recognize that policies adopted today may vary significantly in how their attractiveness would change as uncertainty is reduced in the future. The benefits and costs of proposed policy actions should be evaluated under a broad range of outcomes that reflect the significant uncertainties that pervade the global climate issue. Flexible policies that can easily be reversed or expanded, and policies that can be justified for reasons other than climate change should be highly valued. This approach has been promoted by the United States in the international community since Secretary Baker's February 1989 address to the Response Strategies Working Group (RSWG) of the IPCC.

III. ADAPTATION: LIVING WITH GLOBAL WARMING

This section considers the economic costs of global warming as described in Section II.B., above. We begin with an overview of the general effects of climate change on the economy. The rest of this section then considers the specific effects and related planned adaptation policies on which most attention has been focused, concentrating on the period between now and the middle of the next century.

A. Climate and the Economy

Climate change can affect economic activity both directly, by altering production possibilities, and indirectly, as adaptation to change and its direct effects alters demands for and supplies of particular goods and services. For example, warming would directly affect operators of ski areas and indirectly affect manufacturers of ski equipment.

The direct economic effects of climate change would be concentrated primarily in agriculture, forestry, and fisheries, which currently account for about 2 percent of U.S. GDP and about 5 percent of world GDP. In addition, a rise in the sea level could inundate valuable dry land, and some have argued for substantial adverse direct effects on human health. The construction industry could benefit directly from reduced seasonality, and hydropower production would be affected by changes in precipitation and runoff. The subsections that follow focus on the most-discussed direct effects of global warming. Because of gaps in both science and economics, we have comprehensive impact cost estimates only for agriculture and comprehensive adaptation cost estimates only for sea-level rise.

The indirect effects of climate change will create winners and losers throughout the United States and global economies. If energy use is not curbed to reduce greenhouse emissions, for instance, electric utilities and their suppliers could be important winners. (The EPA estimates that a summer temperature increase of 6.7°F would require an increase in electric generating capacity of between 25 and 50 percent of current capacity.) Demand for air conditioners and heat exchangers would rise, benefiting producers of these products. Producers and distributors of space heating equipment, heating fuels, and winter clothing would likely face decreased demand. Using existing econometric models, it is not generally possible to translate qualitative assessments of this sort into quantitative estimates.

The costs of adaptation would depend critically on how rapidly warming occurs. Useful lives of plant and equipment tend to be substantially less

than 50 years, so that even a steady change in climate over the next century would permit considerable change in the location and composition of economic activity without major disruptions. If sudden changes were required, the values of some immobile assets would drop sharply, and disruptions would occur. Sudden population shifts, for instance, would lead to abandonment of infrastructure in some areas along with the need for major new investments in other areas.

B. Agriculture

Climate change could affect U.S. agricultural markets directly through changed domestic yields and indirectly through changed world prices and trade flows brought about by changed crop production abroad. While a number of possible planned adaptation policies have been identified, their likely costs and effects have not been fully analyzed.

1. Potential Yield Effects. Unfortunately, as noted in section II.B, even given an assumed level of global warming, available predictions of regional temperature, seasonality change, precipitation, and soil moisture vary greatly, leading to highly uncertain agricultural projections. In addition, agricultural effects would vary over time if climate continued to change with gradual increases in atmospheric trace gas concentrations.

Recent studies of the effects of climate changes on crop yields include Smith and Tirpak (1989), Parry, et al. (1988a, 1988b), and Santer (1985). These studies suggest that middle latitude yields would fall and northern latitude yields would rise with a doubling of CO₂ levels and consequent warming.

These estimates do not incorporate important factors such as farm management response with existing technology, the development of new crop varieties better suited to new climate and ambient CO₂ conditions, irrigation costs, and changes in the distribution of agricultural pests and diseases. For example, temperature increases may extend the geographic range of some

crop insect pests currently limited by temperatures (Smith and Tirpak, 1989). Climatic warming may also increase the geographic distribution of livestock diseases, even allowing some livestock diseases that are presently limited to tropical countries to spread into the United States. The rate of many of these changes would likely be small compared to current year-to-year variability.

Most crop modeling results point to 10-20 percent declines in yields in the Southern United States and slight increases in the Northern United States. However, a recent workshop (National Climate Program Office, 1989) that discussed some of these factors concluded that the net effect of trace gas doubling would be to increase yields in all countries by 15 to 40 percent. On the other hand, some argue that the workshop assumed an optimistic change scenario (3.8°F warming and a 15 percent increase in precipitation) and did not consider changes in pest activity or possible summer droughts.

2. Economic Implications. Because national agricultural markets are linked by international trade, the net effect of climate change on any country will depend on how changes in regional climates affect global agriculture, and how these changes affect agricultural prices and trade flows. Because the United States is a large net agricultural exporter, economic losses associated with domestic declines in crop yields could be partially, fully, or more than fully offset by producer gains from the higher agricultural prices that would occur if world supply tightened. The same mechanism would, of course, operate to offset the economic gains stemming from yield increases that some believe could follow from increases in atmospheric concentrations of CO₂.

Kane et al. (1989) used an international trade model (Roningen, 1986) to estimate the economic effects of changes in agricultural yield induced by climate change. That analysis, which deals only with major grain and oilseed crops and does not consider fruits, vegetables, poultry, or livestock, has been updated by USDA for this report. Crop yield range estimates are a synthesis of recent suggestions (Parry, et al. 1988a, 1988b; United Nations,

1989). These estimates, summarized in Table III.1, are largely illustrative because of the high degree of uncertainty concerning the regional yield effects of climate change; note in particular that, in contrast to the NCPO exercise discussed above, the U.S. yield impact is negative.

This analysis predicts a climate-induced increase in world corn and soybean prices of about 10 percent, since most production of these crops occurs in mid-latitude countries that may be adversely affected by climate changes. The prices of all other primary agricultural commodities are estimated to decline, though prices of oil and meal would rise.

Table III.1
Estimated Economic Welfare Effects in 2050
of Climate-Induced Agricultural Yield Changes

Country/Region	Assumed Percentage Changes in Yields of Major Crops	Estimated Net Welfare Change (1986 \$millions)
United States	-10% to -15%	+194
Canada	-10% to +5%	-167
European Community	-5% to -10%	-763
Northern Europe	+10% to +30%	-51
Japan	-5% to +15%	-1209
Australia	+10% to +15%	+66
China	+10%	+2882
USSR	+10% to +15%	+658
Brazil	No change	-47
Argentina	No change	+95
Pakistan	No change	-50
Thailand	No change	-33
Rest of the World	No change	-67

As Table III.1 shows, these estimated price changes would lead to small increases in net U.S. and global welfare. For individual countries, large domestic yield effects do not necessarily translate into large welfare

effects; welfare effects depend on prices determined in world markets and on flows of imports and exports. Thus, even though yields are assumed to fall in the United States, U.S. net welfare is estimated to increase by just under \$200 million in 2050. (These estimates do not consider adaptation costs, such as the possible need to increase irrigated acreage.)

When these welfare effects are discounted to the present, they are seen to be even less important than Table III.1 might suggest. At a 5-percent annual rate of discount, the present discounted value of the estimated \$1.51 billion of net climate change benefits in world agriculture in 2050 is just \$81 million. Assuming linear growth in net benefits to 2050, the present discounted value of all net benefits over the next 60 years is only \$8.1 billion. To put these numbers in perspective, another application of the model used here found that trade-distorting agricultural policies imposed world-wide costs in 1986 alone of \$31 billion.

Kane, et al. (1989) provide an informative sensitivity analysis. Only when assumed yield reductions in the United States, Canada, and the European Community (EC) are set at a very high level (greater than 40 percent), do welfare effects become greater than 1 percent of GDP in the countries studied. Thus, even with minimal planned adaptation, it appears that climate-induced changes in agriculture should not produce major national-level economic effects, positive or negative, by the middle of the next century. However, the possibility of substantial variation in regional impacts cannot be ruled out.

3. Adaptation. U.S. agriculture can improve its resilience to climate change through several adaptive strategies. These include increasing irrigation and water use efficiency, developing and planting heat- and drought-resistant crop varieties, enhancing soil and water retention through use of low tillage and crop rotation practices, maintaining and enhancing the genetic and technological diversity of agricultural systems, and improving pest control techniques in anticipation of possible northward migration of pests. Agricultural policies and programs, such as price support and acreage

control policies, should be reviewed to determine whether there exist modifications that would help ensure timely and efficient adjustment to possible climate change and that would contribute to trade and other policy goals.

C. Sea-Level Changes

The adverse effects of possible sea-level rise on coastal infrastructure, recreation, and coastal ecology could be either large or small. The severity of these effects will be determined by the magnitude and rate of any sea-level rise and whether planned adaptation policies are instituted. Unfortunately, only a few estimates of the costs of sea-level rise or of adaptation policies are available.

1. Possible Impacts. A foot of sea-level rise can erode a typical beach 100 to 300 feet; a 40-inch rise could translate into 900 feet of erosion. The U.S. coastline, as that of most other industrial maritime nations, has been extensively developed, with buildings often within 100 feet of the sea. Even if currently densely developed areas were protected, losses of dryland and coastal wetlands could be substantial if rates of rise were rapid.

The loss of land by erosion and flooding due to accelerated sea-level rise would translate into lost economic services. Gibbs (1984) estimated that the present value (using a 3-percent discount rate and in 1980 dollars) of lost economic services to Charleston, South Carolina, due to an 83 centimeter rise in sea level could be \$1.3 billion. However, planned adaptation could reduce this loss by 65 percent to \$0.4 billion. The amount of rise considered in this analysis is more than double the high end of the most recent IPCC estimate of likely sea-level rise by 2050 if significant warming occurs.

Other nations could also face losses from any sea-level rise. A one-meter rise would inundate 7 percent of the land (occupied by 5 percent of the population) in Bangladesh. Egypt would lose 12 percent of its habitable land,

affecting 14 percent of its population. The cost to each nation could exceed 2 percent of GDP. No estimates are available for the effects of the 25 to 40 centimeter sea-level rise considered most likely to occur by 2050 if significant warming occurs.

Higher sea level would allow the saltfront of rivers to travel further upstream than before and could also allow high salinity water to contaminate groundwater. Hull and Titus (1986) found that with a one-meter rise in sea level, reservoir capacity would have to be significantly increased to allow Philadelphia to continue withdrawing its drinking water from the Delaware River. New York City, which withdraws water from the Delaware headwaters, would also be affected. Less than \$1 billion (\$180 million to \$908 million) in present value capital outlays would be needed to compensate for this possible reduction in water supply following from climate change. (The present values are derived from estimates of \$2.8 to \$14 billion in undiscounted 1986 dollars cited by EPA, assuming a 5 percent real discount rate with all expenditures incurred in 2050.)

Without significant changes in its water management plans, Miami's primary source of drinking water would be rendered unusable by salinity increases if a one-meter rise in sea level occurred. Even with action, the city would face reduced supply. Many other communities along the coast could feel similar effects on their drinking water supplies if such a large sea-level rise were to occur.

Storm surges would be likely to increase in height by the amount of sea-level rise, making flood damages more frequent and severe. The size of flood plains would likely increase. As a result, flood insurance costs would probably go up, even with anticipatory policies.

3. Adaptation. It would not make economic sense to protect the entire U.S. coastline against any substantial sea-level rise. If the sea level were to rise gradually and predictably, substantial costs could be avoided by discouraging additional development or replacement construction in

low-lying areas (perhaps in part by altering Federal flood insurance policy). Particularly for less developed areas, discouraging development would allow beaches to maintain their natural form, wetlands to migrate landward if rates of sea-level rise are moderate, and flood and storm damage to be minimized.

It might, however, also be necessary to nourish recreational beaches with sand and to use levee systems to protect some densely developed shoreline areas. Estimates from Smith and Tirpak (1989) of the costs of these actions through 2100 under alternative sea-level rise assumptions, along with the resulting loss of drylands and wetlands, are shown in Table III.2. (To put the estimated dryland losses in perspective, the land area of Florida, which would be particularly hard-hit by substantial sea-level rise, is about 54,000 mi².) As this table suggests, while densely developed shoreline areas could be protected against likely sea-level rises at moderate (present value) cost, significant losses of drylands and wetlands would occur.

Table III.2
Protecting Densely Developed Shoreline
Areas from Sea-Level Rise

	Sea-Level Rise by 2100			
	Baseline*	50cm	100cm	200cm
Cumulative Costs to 2100 (1986 \$billions)				
Present Value**	0.6-0.8	3.9-5.3	9.0-13.7	20.8-38.1
Undiscounted Sum	4.8-6.2	32-43	73-111	169-309
Dryland Lost (mi ²)	1500- 4700	2200- 6100	4100- 9200	6400- 13,500
Current Wetland Lost (percent)	9-25	20-45	29-69	33-80

* Assumes current rate of sea-level rise, 12cm per century.

** Assumes rate of spending rises 1 percent per year; uses 5 percent real discount rate (continuous time).

D. Human Health

The impacts of global warming on human health are extremely controversial, and the scope for planned adaptation is unclear.

1. Possible Impacts. The consensus view of a recent National Research Council Workshop (1987, p. 19) was that "...long-term climatic changes in temperate latitudes are unlikely to have major health implications." In their comments on a draft of the 1990 Economic Report of the President, HHS (Tompkins, 1989) asserts that "...global warming by several degrees would pose no direct health risks whatsoever..." and notes even though Atlanta's climate is much warmer than New York's, there is no evidence of a climate-induced difference in health risk.

On the other hand, a recent EPA report (Smith and Tirpak, 1989) finds that warming could lead to increases in summertime morbidity and mortality in the United States and the rest of the world. The report notes that any such effects would be more pronounced in some regions than in others and that the extent of acclimatization will play a large role in determining the effects of any actual warming on health. The apparent absence of a climate-related differences in health risk between northern and southern cities and the lesser effect of current heat waves on mortality in Southern cities suggests that human populations could acclimatize, especially if warming occurred over several decades. The EPA report also notes that any warming would probably reduce the number of weather-related deaths in winter months regardless of the degree of acclimatization. The report concludes that it is not clear what the net effect of these two offsetting trends may be, but one of the underlying papers suggests that an overall increase in mortality is most likely.

Several vector-borne diseases, such as yellow fever, dengue fever, and malaria, have the potential to spread northward if the climate warms. For example, the vector of dengue fever breeds year-round in the United States only in southern Florida, but it could move northward by several hundred

miles. The National Research Council Workshop (1987, p. 19) concluded that the expansion of ranges of tropical disease vectors "would mostly affect developing countries." Public health facilities in these nations could not readily handle a dramatic increase in infectious disease with their current resources. Their future ability to cope would depend largely on the rate of improvement in living standards.

2. Adaptation. A national watch/warning system could be developed (much like the systems that now warn of hurricanes and severe snowstorms) to advise people when stressful weather conditions are imminent. Immunization programs could be conducted in anticipation of the spread of certain vector-borne diseases into new areas. An improved health screening program could be developed for immigrants. Finally, improved surveillance systems could provide better data on the incidence and spread of infectious diseases.

E. Other Potential Effects

This subsection considers the implications of possible global warming for forestry, fisheries, water resources, and biodiversity. While a variety of possible adverse impacts have been identified in each of these areas, little quantitative analysis has been attempted to date.

1. Forestry. Climate changes could have a significant impact on the forestry industry. Unfortunately, no attempts have yet been made to quantify the economic impact of such changes on producers or consumers. As in agriculture, both yield and price effects are relevant.

a. Possible Impacts. If significant warming occurs, climate-induced changes in U.S. forests could be apparent in 30 to 80 years. Forest ranges could shrink considerably. The southern boundary of forests in the eastern United States could move several hundred to one thousand kilometers north under plausible global change scenarios. The potential northern range could shift by as much as 600-700 km over the next century under these scenarios, but slow rates of natural forest migration could limit the actual movement to

as little as 100 km. Northward migration may also be limited by less fertile soils and decreased sunlight availability in the North. These projections do not account for the favorable effects of CO₂ on water use efficiency and rates of photosynthesis, reductions in freeze damage, or human intervention in the forest migration process.

Changes in forest distribution and composition could have major impacts on timber production, runoff from forests, and recreational opportunities. Dieback along the southern limits of U.S. forests could result in productivity declines in present dominant species of 46 to 100 percent under some plausible scenarios. This estimate does not account for human intervention, such as species transplantation. The response of forests to climate change could also modify runoff patterns and increase the potential for soil erosion.

Forests in other regions of the world would also be affected by significant warming. A recent analysis for the IPCC (Government of Finland, 1989) suggests that boreal forests will become more productive if significant warming occurs. Others believe that these same forests would be especially hard hit, since most climate models suggest that any warming that occurs would be greatest in high latitudes. While temperature increases may be smaller in the tropics, tropical forests could be significantly affected by changes in rainfall and land use pressures that may impede forest migration to more suitable locations.

b. Adaptation. Today's forest management decisions could have long-term impacts on the composition and location of forests. Planned adaptation measures that could be considered include maintaining forest diversity and extensiveness to enhance the ability of forests to respond to a range of climatic conditions; developing and testing fast-growing and heat- and drought-resistant species; preparing for dieback along southern boundaries with plans for rapid harvesting and removal of dead trees and replacement with better adapted species or non-forest systems; improving capabilities to monitor for changes in forest growth and composition; and modifying pest and

fire control strategies to reflect likely changes in the frequency and nature of these disturbances.

2. Fisheries. The effects of global warming on fisheries depend primarily on changes in regional climates and ocean circulation and on the pace at which they occur. The qualitative effects of warming on fisheries are thus highly uncertain, and no quantitative economic analysis has, to our knowledge, been attempted.

a. **Possible Impacts.** The impacts of any significant change in temperature on fish populations would vary across species. Some would experience increased habitat and associated expansion of range. Adaptation would be easier for fish in large bodies of water, including the oceans, than for those constrained in small water bodies. Total productivity of fishing grounds in the Great Lakes and oceans could increase. Under some scenarios, phytoplankton and fishery productivity could increase in the Great Lakes by 1.6 to 2.7 fold, but there is the potential for a decrease in diversity due to intensified species interactions. Climate change effects on the ocean are particularly uncertain due to the complexities surrounding ocean circulation, which until recently has not been explicitly considered in climate models, heat uptake by the ocean, and future patterns of nutrient upwelling. One study found that many Gulf Coast fish and shellfish would be unable to tolerate much higher temperatures.

If there is rapid sea-level rise and resulting saltwater intrusion and wetlands loss, changes in the distribution and size of many estuarine species would be possible. Any losses of coastal wetlands would adversely affect fish. Less salt-tolerant species would tend to migrate upstream towards suitable habitat, ceding present habitats to more salt-tolerant species. In lakes, streams, and estuaries, declines in water quality due to reduced dissolved oxygen levels at the higher temperatures in some scenarios could adversely affect many recreational species.

In the tropics, species dependent upon coral reefs could experience significant adverse effects. Coral reef ecosystems could be vulnerable both to increased thermal stress and to sea-level rise, if it were rapid enough to inundate and kill the coral species.

b. Adaptation. Both the need and the opportunity for planned adaptation appears to be limited. Commercial fishing occurs primarily in the ocean, where effects of possible climate changes are especially uncertain. Changes in species location and composition could require some adjustments, but commercial fisheries now make similar adjustments in response to overfishing and the natural movement of species. Travel time to specific commercial fisheries may rise or fall, and changes in available species may raise or lower equipment cost. If equipment adjustments were made gradually, as durable assets were replaced, their costs would be relatively small.

Management of water flow to lakes and streams could affect fish populations in those water bodies. Restocking, which already plays an important role in recreational fisheries, and new species introduction could aid in adaption to climate change. Reducing water pollution could offset adverse warming impacts on some species.

3. Water Resources. Even if an assumed rise in regional temperature is taken as given, it is difficult to predict the impacts of climate change on water basins with much confidence because of uncertainties about regional precipitation. The quantitative estimates that follow assume a U.S. temperature increase of 5.4°F to 9°F and an annual precipitation increase of 1 to 3 inches.

a. Possible Impacts. Such higher temperatures would likely reduce snowpacks by shortening the snow season and causing more precipitation to fall as rain. This could have a significant effect on the operation of such water systems as the Central Valley Project and the State Water System in California. With no change in infrastructure, earlier snowmelt would raise flood probabilities in the winter. Management response to this would reduce

annual deliveries by 7 to 16 percent. Similar problems could be expected in other Western water management systems.

Because of uncertainties about rainfall, it is hard to estimate the direction of change in water supply in many regions. This is especially true for rivers that are not fed by snowpacks, such as many rivers in the Southeast. Higher temperatures could lower many lake and reservoir levels through the effects of increased evaporation that was not offset by increased rainfall. For example, the levels of the Great Lakes could fall by an average of 0.5 to 2.5 meters, which could, among other things, reduce dilution capacity. On the other side of the coin, the Great Lakes would benefit from a longer shipping season and a reduction in water pollution due to reduced use of salt and other chemicals to cope with ice and snow.

If adverse developments occur, future costs would be incurred. For example, the future costs of building additional reservoirs for the California systems could be over \$500 million (undiscounted) and the costs of dredging harbors and making other adjustments could cost \$270 to \$540 million (undiscounted) along the Illinois shoreline alone. (Note that a \$500 million outlay required in 2020 could be financed from the proceeds of an investment of only \$116 million today, assuming a 5 percent real rate of return on invested funds.)

The implications for water quality are mixed. Dissolved oxygen levels could be lower because oxygen is less soluble in higher temperature water and because higher temperatures may increase primary aquatic productivity, which increases the demand for oxygen. Summer stratification could be lengthened in some lakes, which, combined with higher demand for oxygen, would reduce dissolved oxygen levels and harm aquatic life. These factors could lead to lower water quality in some basins. However, reduced use of chemicals to cope with ice and snow would contribute to improved water quality in some northern areas.

b. **Adaptation.** A number of measures could be taken to increase the resiliency of water resources to climate change. Water conservation could be promoted by reducing or eliminating subsidies for water use or allowing trading of market rights. Water resource managers could be encouraged to explore ways to transfer water between neighboring systems during droughts and to consider plausible climate change in sizing new long-lived facilities. New drought-resistant species could be developed to help cope with any water shortages in agricultural areas.

4. Biodiversity. Other effects of possible global warming include a possible decline in biodiversity stemming from the loss or change of habitats that result in the decline or loss of some animal and plant species. While the relevant mechanisms can be described, their effects under different climate change scenarios have not been estimated.

a. **Possible Impacts.** Changes in climate would harm some species but benefit others. The ability of a natural community to adapt to changing climatic conditions would depend on the rate and character of climate change, the size of species ranges, the dispersal rates of individual species, and whether or not barriers to migration are present. A species' ability to adapt to changing climatic conditions would be heavily influenced by dependencies upon or competition with other species within the ecosystem. For this reason, the impacts of climate change on natural communities are difficult to predict.

In general, communities near the edge of a species range and arctic communities would be at particular risk from significant climate change, as would species that migrate slowly, that are already threatened or endangered, that are specialized to small and isolated environments (such as montane and alpine communities) or that have narrow habitat requirements. In some cases, man-made barriers may limit migration: examples include mammals isolated in refuges and prairie species blocked by expansive agriculture.

b. **Adaptation.** Existing programs that focus on the protection of endangered species and preservation of genetic diversity could be adjusted if

the number of species at risk grows. Expansion of reserves and creation of migratory pathways between areas of suitable habitat could enhance our ability to preserve species. It may be useful to develop forest management practices that allow product extraction while minimizing any reductions in an area's future use as wildlife habitat. Areas that may become suitable future habitat for threatened and endangered species, such as lowland areas adjacent to current wetlands, could be identified and considered for protection.

IV. MITIGATION: LIMITING GREENHOUSE GAS EMISSIONS

As indicated in Section II, the analysis of mitigation strategies must consider emissions of multiple gases arising from many different economic activities in many nations. The first subsection provides some basic assumptions and principles about alternative policies for reducing greenhouse emissions. Estimates of the costs of reducing emissions of each of the main greenhouse gases are then discussed. The costs of reducing carbon dioxide and chlorofluorocarbon emissions have received the most attention. Estimates of carbon dioxide abatement costs remain preliminary and controversial. Relatively little is known about the costs of reducing emissions of other greenhouse gases. Major studies of mitigation policies area are underway within the Federal government (in DOE, EPA, DOI, and OTA; a CBO study will shortly be published), foreign governments (a major Japanese (MITI) study will be completed by March 1), and in the private and non-profit sectors (work is underway at EPRI, Harvard, MIT, and Stanford). A revision of this section within a year or two from now could rely on a much deeper research base and might have different policy implications.

A. Background

Two points are basic to any discussion of mitigation policies. First, global action is essential if meaningful results are to be obtained without bringing economic growth to a halt in some regions. Second, as in other

regulatory arenas, mitigation policies should minimize costs by relying to the maximum possible extent on incentives and by providing flexibility.

1. Global Action. Table IV.1 summarizes some key data from Section II. Anthropogenic emissions of methane (CH₄) and nitrous oxide (N₂O) are mainly agricultural in origin and are mainly produced by the developing nations; it is clear that global action, concentrating on agriculture, would be necessary if a decision were taken to control CH₄ and N₂O emissions. While current CFC emissions are mainly produced by OECD member states (which have already pledged significant reductions and are likely to commit to a near total phaseout), CFC emissions of other nations are predicted to rise rapidly in the future if no additional controls are put in place. Finally, while the OECD nations are now the single largest source of anthropogenic carbon dioxide (CO₂) emissions, emissions of other nations, which already account for more than half of total emissions, are expected to increase rapidly absent serious mitigation efforts. The OECD share of CO₂ emissions is projected to fall below 25 percent by 2050. Taking account of expected future emissions patterns, the need for global action is evident for these gases as well.

Table IV.1
Anthropogenic Greenhouse Gas Emissions

Gas	Percentage Share of Radiative Forcing in the 1980s	<u>Percentage Share of 1985 Emissions</u>		
		OECD Nations	USSR/East Europe	CP Asia/ Developing
CO ₂	49	43	22	35
CH ₄	19	25	13	66
CFCs	14	65	16	18
N ₂ O	5	27	14	59

Table IV.2 considers the effect on global CO₂ emissions in 2025 of the unilateral adoption by the U.S. or by all OECD nations of four frequently-discussed emission limitation targets: reduction of emissions growth by 50 percent, stabilizing emissions at 1985 levels by 2000, reducing emissions 20 percent below 1985 levels by 2005, and reducing emissions 50 percent below 1985 levels by 2025. Though the underlying global and regional emission scenarios on which the calculation is based are necessarily uncertain, the basic message of this table is fairly robust: even drastic reductions by all OECD nations cannot prevent substantial increases in world CO₂ emissions by 2025. Unilateral actions by the U.S. have even smaller effects.

Table IV.2

Global Effects of Unilateral CO₂ Emission
Reductions by the United States or the OECD
(Index of Global Emissions: 1985=100)

Emissions Policy	Global CO ₂ Emissions in 2025 if Policy Adopted by	
	U.S. Only	All OECD
None (Base Case)		207
Reduce Growth by 50%	203	198
Stabilize by 2000	203	198
Reduce 20% by 2005	194	182
Reduce 50% by 2025	188	169

Note: Based on RCW scenario in Lashof and Tirpak (1989), using 1985 emissions as the baseline.

Table IV.3 considers the implications of meeting the emission policy targets of Table IV.2 on a global basis if nations outside the OECD take actions that are significant but less than proportional to the targets. The table shows that without full participation by other nations, the OECD member

states would have to make dramatic or impossible cuts to meet widely-discussed global CO₂ emissions goals.

Table IV.3

OECD CO₂ Emissions Reductions Required to Achieve Global Goals
When Other Nations Take Lesser Actions

Global Goal	Action Assumed Taken by		Required OECD Reduction
	USSR/E. Europe	Developing Nations	
Cut Growth 50%	Growth cut 25%	None	98% by 2025
Cut Growth 50%	Growth cut 25%	Growth cut by 25%	33% by 2025
Stabilize by 2000	Growth cut 50%	Growth cut by 25%	41% by 2000
Stabilize by 2000	Growth cut 50%	Growth cut by 50%	29% by 2000
Cut 20% by 2005	Stabilize	None	Exceeds 100%
Cut 20% by 2005	Stabilize	Stabilize	46% by 2005
Cut 50% by 2025	Cut 20% by 2025	None	Exceeds 100%
Cut 50% by 2025	Cut 20% by 2025	Cut 20% by 2025	89% by 2025

Notes: Based on RCW scenario in Lashof and Tirpak (1989), using 1985 emissions as the baseline. Developing Nations include Centrally Planned Asia.

2. Differential Impacts. While global action may be essential for effective mitigation, differences in costs and benefits among nations may make it difficult to obtain global agreement on specific policies. Table IV.4 shows that CO₂ emissions per capita and per dollar of GNP vary substantially. Among those countries for which GNP estimates are available, higher-income nations tend to have higher emissions per capita but lower emissions per dollar of GNP. The USSR and Eastern European countries have particularly high emissions. These variations make it easy to imagine an international replay of the "clean states v. dirty states" debates that have marked Congressional

consideration of acid rain proposals. The stakes for oil-exporting nations may be particularly high (Whalley and Wigle, 1989).

The United States has a relatively high per capita CO₂ emissions rate for two reasons. First, U.S. energy intensity (as measured by BTUs consumed per constant dollar of GNP) is higher than that of most of our major competitors. It is double that of Japan and 75 percent above that of Western Europe. Second, coal provides about 27 percent of total U.S. energy requirements. Among major industrial countries, this share is exceeded only by the U.K. (32 percent) and West Germany (29 percent). The United States also relies less heavily on nuclear power than do many other industrialized countries.

Table IV.4
CO₂ Emissions Per Capita and Per Dollar of GNP, 1986

Country	Per Capita (tonnes of Carbon per capita)	Per Dollar of GNP (kilograms of Carbon per dollar)
United States	5.005	0.28
Canada	4.094	0.29
Japan	2.109	0.16
West Germany	3.066	0.25
Australia	3.853	0.32
France	1.794	0.17
United Kingdom	2.938	0.33
Italy	1.655	0.19
Spain	1.284	0.26
Poland	3.321	1.60
Mexico	0.909	0.49
South Africa	2.785	1.51
Brazil	0.379	0.21
China	0.527	1.76
India	0.187	0.64
East Germany	5.499	n.a.
Czechoslovakia	4.212	n.a.
USSR	3.593	n.a.
Romania	2.408	n.a.

Notes: From Department of Energy and World Bank Development Report, 1988.
Top set of countries listed from highest to lowest GNP per capita.
Includes emissions from fossil fuel combustion and cement production only. "n.a." means GNP not available in the sources employed.

Because the United States relies heavily on coal, the fossil fuel with the highest amount of carbon per unit of energy, for electricity generation, U.S. electricity rates would be likely to rise more than those in other industrialized countries if concerted action were taken--for example, by imposing the same charge on the carbon content of fossil fuel--to curb CO₂ emissions. Unless energy-intensive U.S. industries were able to greatly

increase their energy efficiency, they could be disadvantaged relative to major foreign competitors who would be less affected by electricity rate increases.

In addition, because the United States has an abundance of coal reserves, but only limited reserves of oil and gas, and very little undeveloped economical hydroelectric potential, limits on coal use would likely result in larger imports of oil and gas, which will have implications for our balance of trade or energy security. All of this presents a marked contrast to the 1973 and 1979 oil shocks, where our greater self-sufficiency in energy provided an advantage relative to most other industrialized nations. On the other hand, some argue that in the longer run, our more energy-efficient competitors will find it harder to reduce emissions, since they have already undertaken cheap efficiency measures that we have not.

Since adaptation costs are likely to vary substantially among nations, so may interest in investing in mitigation. Existing models suggest greater warming in high northern latitudes, and less warming in latitudes where most developing nations are located. There is likely to be considerable regional variation in agricultural effects. Nations differ substantially in their vulnerability to sea-level rise. A higher share of GNP originates in climate-sensitive activities in developing nations, but these nations generally lack resources for adaptation. In short, while global action is essential to significantly limit greenhouse emissions, differences among nations may make it difficult to find universally acceptable emissions targets or ways of sharing the costs involved.

3. Incentives and Market Failures. Consistent with its approach to domestic regulatory issues, this Administration feels that an approach to limiting net anthropogenic greenhouse emissions that encompasses all important greenhouse gases and gas sinks as well as gas sources is more promising than one that considers each source of greenhouse gases individually. An international limitation agreement based on the comprehensive approach, for example, would allow each nation to devise a strategy that reflects its own

situation regarding opportunities for emissions reduction and sink enhancement. The Administration also feels that any set of nations should be free at any time to develop a joint strategy to meet their pooled ceilings, as long as net global emissions are not thereby increased. An approach incorporating these principles was outlined in a U.S. concept paper tabled at the IPCC.

Even if a comprehensive approach with provision for pooling were accepted, opinions are divided on how individual nations--in particular the United States--should set domestic policy to meet net emission limitation targets. Administration regulatory policy generally holds that primary reliance should be placed on incentive-based approaches--including charges, user fees, and tradable emissions rights. This view follows from the presumption that households and firms generally respond rationally to incentives, so that regulatory goals are met at least cost by providing proper incentives and maximal flexibility to respond at all points along the production-consumption chain.

A second school of thought tends nonetheless to favor the use of efficiency standards and other command-and-control techniques. Adherents of this school point to apparent widespread deviations from best practice in energy use and to reports of large payoffs from utility conservation programs as indicating market failure. They contend that government regulation can reduce CO₂ emissions, in particular, at low or even negative cost by helping or forcing individuals to take actions that are, in fact, in their own self-interest.

Market failures do not, of course, provide an automatic justification for direct regulation. Market failures, where they exist, can be addressed directly. For example, since utility profits under traditional State rate regulation are often linked directly to the level of electricity sales, a utility faced with capacity constraints would usually prefer to increase supply rather than reduce demand. Regulatory changes at the State level could

be made to place the alternatives of demand reduction and supply augmentation on a more even footing. Public information programs, promotion of efficient appliances by utilities, and changes in mortgage qualification rules to reflect appliance operating costs are other steps that could be used to deal with market failures directly.

The Administration's regulatory philosophy recognizes that efficiency standards and other command-and-control regulations have several significant disadvantages relative to incentive-based systems or approaches that address perceived market failures directly. First, the burden of meeting standards cannot be reallocated across industries or across the different greenhouse gases in private cost-saving transactions. Second, in the absence of price increases for fossil fuels, standards can increase the demand for energy-using services. Finally, standards reduce the range of products available to meet diverse consumer needs.

The costs of efficiency standards are often hidden rather than explicit. For example, a higher average fuel economy standard might be met by forcing consumers to buy only the more fuel efficient and generally cheaper vehicles in the existing product line, actually reducing their purchase and gasoline costs. However, out-of-pocket costs do not reflect costs imposed on consumers by denying them the option to purchase other valued attributes such as safety, performance and spaciousness. Higher fuel efficiency without higher fuel prices also lowers the per mile cost of driving, encouraging additional trips, fuel consumption and emissions. Since fuel economy labels already provide good information to auto purchasers, and there are few apparent institutional rigidities in this market, the economic rationale for stringent vehicle efficiency standards is doubtful at best.

More generally, assertions that efficiency improvements are cost saving or nearly costless raise the classic question of why these improvements are not automatically taking place. Such assertions must be examined to see if the claimed efficiency gains involve tradeoffs with other product attributes that were excluded from the analysis.

Efficiency standards based on national average values may actually serve to restrict the choices of only those consumers who face low energy prices or have low usage rates (and thus energy consumption) for the product. Those with high usage rates or those who face high energy prices would purchase high efficiency products even in the absence of mandatory standards. Taking this self-selection into consideration, an efficiency standard that appears to save money on the national level may actually impose costs on many consumers.

Economic models populated by perfectly rational firms and households participating in perfect markets that are always in equilibrium clearly do not provide a fully realistic characterization of the U.S. economy. But the alternative extreme assumption, of widespread private waste easily corrected by regulation but untouchable by market incentives or direct correction of market failures, seems at least as far off the mark. The question of where truth lies between these extremes is ultimately empirical, and it cannot be answered here.

It is important, however, to point out that essentially all analysts of agree that some reductions in greenhouse gas emissions can be obtained at low cost. Disagreements focus on how fast the marginal cost of abatement rises and on how the initial, low-cost reductions can best be obtained.

B. Carbon Dioxide

Carbon Dioxide (CO₂) accounted for about 49 percent of the increase in radiative forcing in the 1980s and is expected to account for a larger share in the future. The Administration's acid rain proposals, by providing incentives to conserve electricity, will reduce CO₂ emissions from electric utilities by around 2 percent--and will thus reduce total U.S. fossil fuel CO₂ emissions by around 0.7 percent. The higher CAFE standards adopted last spring will be likely to slow the increase in CO₂ emissions from automobiles.

Below, we begin by considering the estimated costs of CO₂ emissions reductions produced by economy-wide models. These models generally assume that markets work well, so that incentive-based approaches minimize the costs of emission reduction. We then consider analyses of the ability of regulatory initiatives to reduce emissions. These analyses tend to be sector-specific and focus on market or policy failures. The final two subsections focus on the potential of new technologies and of forestation policies.

1. Economy-Wide Analyses of Emissions Limitation Costs.

Several recent studies, and work now in progress on which we have been briefed, attempt to estimate the costs of efficient reductions in CO₂ emissions levels, using three distinct economy-wide modeling frameworks. Energy/economic balance analysis focuses on the long-term relationship between energy use and output, without explicit consideration of substitution possibilities within the energy sector or the economy as a whole. Energy policy models also focus on the long run but explicitly incorporate substitution possibilities among fuels and the responsiveness of overall energy demand to changes in energy prices and income levels. These models often incorporate a crude feedback from energy to GNP, but the main causality runs from the economy to the energy sector rather than vice versa. Energy-economic models, which exist in both short- and long-term variants, attempt to incorporate a fuller two-way link between the energy sector and the economy at large, but they tend to include less detailed treatment of energy production and consumption. While all of these approaches have clear weaknesses that point up the need for further research and the development of more comprehensive models, each provides some useful information, and all are considered here.

Costs are estimated in models of the latter two varieties by comparing economies with and without emissions reductions. Assumptions about emissions growth in the no-policy baseline case vary widely and contribute to the diversity of results obtained. Assumed annual growth rates in CO₂ emissions through 2050 vary from 0.61 percent (Edmonds, et al., 1986) to 2.27 percent

(Edmonds and Reilly, 1983). Even small differences in baseline annual emissions growth rates (BAEGRs) can have a major effect on levels of emissions over the long time intervals considered in global climate analysis. For example, an increase of average annual emissions growth from 0.6 percent to 1.6 percent translates into a 43 percent increase in annual emissions levels by 2050. Higher BAEGRs translate into higher, sometimes much higher, costs of meeting particular target emissions levels.

For high BAEGRs, even quite draconian policies do not significantly shift the date at which atmospheric CO₂ concentrations double from preindustrial values. For lower BAEGRs, policies to stabilize emissions appear to be more feasible. The different scenarios evaluated in the models considered below are best thought of as illustrative scenarios--possible sets of internally consistent future developments--rather than as definitive forecasts.

While the studies discussed below differ in many respects, and their shortcomings point up the need for further economic research, they all suggest that the costs of stabilization or reduction of CO₂ emissions will be high--at least 1 percent of GNP per year for commonly discussed goals such as the indefinite stabilization of emissions between 80 and 100 percent of present levels. One percent of current world GNP is about \$150 billion; if world GNP grows at an average annual rate of 3 percent, the total cost to 2050 (discounted at 5 percent) of 1 percent of GNP per year would come to about \$5.2 trillion. If economic growth is significantly slowed, costs could be much higher.

a. Energy/Economic Balance Analysis. Kaya (1989) and Kaya, et al. (1989) work from the following identity:

Growth rate of CO₂ emissions =
 growth rate of CO₂ emissions per unit of energy use
+ growth rate of energy use per unit of output
+ growth rate of output

A -1.0 percent growth rate of energy use per unit of output is assumed, along with a growth rate of CO₂ per unit of energy use of, between -0.4 and -1.0 percent. The former estimate may be viewed as somewhat pessimistic, especially if a substantial rise in energy prices occurs. The latter estimate is rather optimistic given the likelihood of increasing reliance on coal and coal-based synthetic fuels that are highly carbon intensive.

Under these assumptions, a CO₂ emissions growth rate of -1.0 percent, which is necessary to implement a 20 percent cut in emissions by 2005, is associated with world output growth of 0.4 to 1.0 percent per year. Over the last several decades, output has grown at 4 to 5 percent annually, and population has grown at a 2 percent rate. Thus these calculations call for a drop in output growth of 3 to 4 percentage points per year, leading to an almost certain decline in per capita income.

Even if CO₂ limitations reduced output growth by only 1 percentage point (i.e., from 3 percent to 2 percent), the long-run effect on the world economy would be staggering. The cumulative cost from now to 2050 (using a 5 percent discount rate) would be \$107 trillion dollars--just over 7 times world output in 1987. This reduction in growth would depress output in 2050 by about 45 percent.

On the other hand, experience following the 1973 and 1979 oil shocks indicates that the relationship between economic growth and energy use may be less rigid than Kaya's framework suggests. Between 1973 and 1985, the price of energy rose by 47 percent relative to non-energy products at the consumer level and by 80 percent at the industrial level. Partly as a consequence, the ratio of energy use to real GNP fell by 2.4 percent annually in the United States and 1.9 percent annually in the OECD countries. CO₂ per unit of energy also fell during this period, as usage of natural gas and nuclear power increased rapidly, and U.S. and OECD CO₂ emissions were essentially constant between 1973 and 1985.

This was not a period of economic boom, however; growth rates of U.S. output and productivity over the 1973-85 period, 2.3 percent and 1.0 percent respectively, were far below the corresponding rates of 3.7 percent and 2.9 percent for the 1948-73 pre-shock period. While most of the slowdown in growth can be attributed to other factors, higher energy prices played an important role. The rise in energy prices led to a substitution of other inputs for energy and a diversion of investment that might otherwise have been used to increase labor productivity.

Moreover, part of the decline in the energy/GNP ratio during 1973-85 reflects the increased relative importance of the service sector. One cannot count on comparable increases in the future, especially as the United States moves from being a large net importer of manufactured products to a large net exporter in order to balance its current account and repay international borrowing.

While the use of natural gas could continue to expand in the near term, the absence of nuclear projects in the pipeline and current strong public resistance to this form of power in the United States suggest it will be harder to substitute nuclear for fossil energy in the future than in the 1973-85 period. On the other hand, many have argued that macroeconomic policies and energy regulation contributed significantly to the poor economic performance of that period, and one can hope that similar policies will not be adopted in the future. Moreover, revenues from a carbon charge (discussed below) could be used to lower other taxes, while much of the increased spending on oil in the 1973-85 period flowed abroad.

Despite these caveats, the period of the oil shocks provides a useful reference for consideration of the likely impact of CO₂ emission reduction policies on output and productivity growth. Energy remains a major input to the U.S. economy, and studies discussed below suggest that energy price increases at least as large as those experienced between 1973 and 1985 would be required to achieve widely-discussed targets for CO₂ emissions reduction.

On balance, there is no reason to believe that any attempt to reduce energy use significantly today would be substantially less economically disruptive than were the oil shocks of the 1970s.

b. Long-Term Energy and Energy-Economic Policy Models. These models allow for explicit analysis of policies that raise the price of fossil fuels to discourage their use. The most natural (and easily analyzed) policies of this sort involve imposition of a carbon charge.

A carbon charge levied on the carbon content of primary fossil fuels at their first sale or entry into the distribution system would provide an administratively simple means of reflecting the social undesirability of greenhouse emissions in fossil fuel prices. Because end users cannot significantly alter the relationship between fuel carbon content and CO₂ emissions, and an economical carbon scrubbing technology is not anticipated in the near future, there is no efficiency advantage in applying the charge to end users. Sellers in long-term energy contracts (especially coal contracts) should not be forced to absorb the charge to fulfill their existing contracts. This problem can be avoided by imposing the charge on the buyer in the first transaction. Depending on other nations' mitigation actions, coal destined for export might be exempted from the charge, and a refundable credit for petrochemical and other uses of fossil fuels that sequester verifiable amounts of carbon could be considered. In principle, imports of electricity generated from fossil fuels should pay a charge based on the carbon content of the input fuel, though this could conflict with our free trade agreement with Canada.

Unlike an ordinary tax, which distorts private decisions such as the choice between work and leisure, an appropriate carbon charge can actually improve resource allocation and raise welfare by closing the gap between the private and social costs of carbon-emitting activities. A carbon charge would affect decisions ranging from the choice among alternative technologies for generating electricity, to the energy efficiency of cars, buildings, and industrial equipment, to the demand for automobile travel and products made

from steel. Because a carbon charge provides incentives that affect decisions at all points along the production-consumption chain and across all industries, it automatically focuses on those activities where CO₂ emissions reductions can be achieved at least cost. The least-cost property of charges when markets work well is useful in placing a lower bound on the economic implications of particular greenhouse gas emissions targets, even if other tools would actually be used for implementation. A carbon charge does not, of course, provide the full flexibility and efficiency of a comprehensive charge system applied across all greenhouse gas sources and sinks.

Existing economy-wide studies generally imply that carbon charges on the order of \$100 per ton or more would be needed to have a significant effect on carbon dioxide emissions. At current prices, and not allowing for fuel market responses, a carbon charge of \$100 per metric ton would increase the average price of coal delivered to electric utilities by 178 percent, the average price of natural gas by 49 percent, and the average price of oil by 70 percent. These impacts are comparable on average to the energy price increases caused by the oil price shocks of the 1970s. Electricity rates would immediately rise by up to 30 percent, 15 times the average increase that would be produced by the Administration's controversial acid rain proposals.

Nordhaus (1989) provides an explicit (albeit necessarily crude) analysis of the costs and benefits of reductions in greenhouse gas emissions. His highly uncertain point estimate of the future costs of warming, based on selected EPA estimates of its effects on sea level, electricity demand, and agricultural productivity is 0.25 percent of future GNP. Even this small impact is sufficient to justify low cost measures, such as significant curtailment of CFCs and a small \$3 per ton carbon charge. At the high end the range of effects that is likely to contain the true effect (anywhere from a benefit of 1.75 percent of GNP to a cost of 2.25 percent of GNP), a carbon charge of as much as \$40 per ton might be justifiable. This analysis suggests that if carbon charges are found desirable in principle, serious consideration should be given to using charges substantially lower than those employed in

the modeling exercises discussed here. Once a carbon charge system is in place, the rate can be relatively easily raised--or lowered--as scientific and economic uncertainties are resolved in the future.

Manne and Richels (1989) simulate policies capable of stabilizing U.S. CO₂ emissions at their 1990 level through 2000 and then reducing them to 80 percent of this level by 2020. Their policy is a charge that begins at \$29 per ton of carbon but rises sharply after the year 2000 before stabilizing at \$250 per ton by the middle of the century. Initially, the emissions limit is met by fuel switching from coal to natural gas. Natural gas, which accounted for 12 percent of electricity generation in 1985, accounts for 27 percent by 2010. The rapid run-up in charge rates after 2000 reflects the difficulty of securing a 20 percent emissions reduction by 2020 in the face of exhaustion of natural gas supplies and prior to the large scale deployment of advanced technology alternatives to fossil fuels. Costs build to about 5 percent of GNP by 2030 and maintain that value through 2100.

However, the costs of meeting the emissions target are significantly reduced if the BAEGR turns out to be lower than the 1.7 percent they assume. For example, a 1 percent autonomous (not linked to prices) improvement in energy efficiency reduces losses to about 3 percent of GNP. The further addition of an optimistic forecast of future energy technology lowers estimated losses to a little more than 1 percent of GNP.

In an early paper, Edmonds and Reilly (1983) use an energy policy model to consider the application of carbon charges in the United States alone and to the entire world. These cases may be viewed as bracketing the outcomes under an international agreement with special provisions for developing countries and/or incomplete participation. The application of stiff carbon fees throughout the world (100 percent change on coal, 78 percent on oil, 56 percent for natural gas, and 115 percent for synfuels, roughly reflecting the different carbon content of the different fuels) beginning in 1985 is found to reduce global carbon emissions by 40 percent from base case levels by 2050.

However, given the high BAEGR employed (2.27 percent) global CO₂ emissions are still three times the current level in 2050. A fee program in the United States alone is much less effective, reducing 2050 global emissions by only 15 percent. Carbon charges in the United States alone depress the world market prices of fossil fuels, leading to an increase in fossil energy use overseas that significantly offsets the greenhouse benefits of reduced energy demand and fuel switching in the United States.

In subsequent work, Edmonds (1989), Reilly and Edmonds (1985), Reilly, et al. (1987), and others have used the same model with a lower BAEGR. Cline (1989) finds that a somewhat higher global charge (approximately \$100 per ton of carbon) than that considered in the original Edmonds-Reilly paper is sufficient to stabilize CO₂ emissions at or slightly below current levels in the second half of the 21st century with a 0.95 percent world BAEGR. The Congressional Budget Office (CBO) analysis of carbon charges (Montgomery, 1989, in progress) presents runs with a 1.2 percent U.S. BAEGR and a 2.0 percent world BAEGR. In these runs, a global \$100 per ton carbon charge cuts a baseline tripling of CO₂ emissions by 2050 to a doubling. The difference between these results and Cline's highlights the importance of the BAEGR in driving the results regarding effectiveness of taxes in meeting target emissions.

Some general observations apply to all runs of this model. First, while some substitution among primary energy sources does occur, the primary mechanism for cutting emissions is a reduction in overall energy use. Second, the burden of greenhouse policy always falls heavily on the coal sector and on net exporters of fossil fuels (and, by implication, energy-intensive products). For example, in Cline's runs, coal use increases between 2000 and 2050 in the baseline case but falls by more than 2/3 when the global charge is applied. Third, while global policies are clearly preferable in CO₂ limitation terms, they are likely to put much more pressure on the world savings-investment balance. Crowding out of other productive investment becomes a larger problem as more countries attempt to increase investment in

energy efficiency at the same time. Indeed, for developing countries with limited access to capital markets, concern over crowding out could pose a serious barrier to any participation in CO₂ limitation efforts. Finally, the Edmonds-Reilly model is not useful for estimating the effects of greenhouse policy on GNP, since the role of energy in the production function and tradeoffs between energy and nonenergy investment are not explicitly modeled.

Work in progress at the CBO will also report on runs of the Jorgensen general equilibrium model with a unilateral \$100 per ton carbon charge imposed in 2000 (Montgomery, 1989). This policy is estimated to reduce real GNP by 1 percent. The Jorgensen model essentially involves a "de novo" solution that does not take into account constraints imposed by current fixed assets and labor force skills on the composition of the economy 10 years from now. The Jorgensen model solution entails radical shifts in the composition of electricity supply and large interindustry shifts in the composition of the economy. Sectors such as textiles, agriculture, and leather grow, while chemicals, mining, and plastics decline.

Because Jorgensen's model describes an economy in 2000 that is very different from today's economy and because adjustments involve costs, such radical shifts are unlikely to occur over this time interval. Such shifts would necessarily entail significant dislocations. Because of these adjustment costs, actual structural changes and thus actual emissions reductions, would likely be lower than these results indicate. Alternatively, much higher economic costs, including significant labor force dislocations and sharp reductions in the value of existing immobile assets, would be required to achieve the level of emissions reduction obtained in the Jorgensen model solution.

The sectoral shifts envisioned by Jorgensen would nonetheless occur over time if significant policies to discourage CO₂ emissions were adopted. These large distributional effects are thus a reminder that the aggregate economic effects of CO₂ emissions reduction policies, variously estimated at between 1

and 5 percent of GNP for carbon charges in the \$100 per ton range, would not be felt evenly throughout the economy.

c. Short-Run Economic/Energy Models. A recent detailed analysis considered the cost to Australia of achieving a 20 percent reduction in CO₂ emissions by 2005 (Marks, et al., 1989). In some respects, such as the significant use of coal in electricity generation, the Australian situation is similar to that of the United States. Using very conservative methodology, attainment of a 20 percent emission reduction is estimated to slow economic growth and cause GNP in 2005 to be at least 1.2 percent below the no-policy baseline GNP levels. Since Australia is a small economy with an open capital market, the investments needed to achieve the emissions target may be possible without driving up interest rates or crowding out other investment.

Short-run economic modeling for the U.S. economy shows that a carbon charge of \$100 per ton would have a significant effect on both CO₂ emissions and economic growth rates (Montgomery, 1989). One widely-used macroeconometric model shows a maximum depression of 2 percent in real GNP from baseline levels over the next decade; another shows a maximum effect of 6 percent. Maximum effects on the overall price level range between 2 and 4 percent. At 1988 energy consumption levels, a charge of this magnitude would raise approximately \$130 billion annually. However, additional debt service costs and higher federal expenditures for cyclically sensitive programs would almost fully offset this additional revenue in the near term. Reductions in other taxes could reduce but not eliminate these macroeconomic effects, but would also lose some of the CO₂ reduction benefits associated with a weaker economy.

d. Energy Sector Impacts. Because coal is at the same time this country's (and the world's) most abundant fossil fuel, as well as the fossil fuel with the highest carbon emissions per unit of energy, it is impossible to construct a plausible scenario for substantial CO₂ emissions reduction without a major adverse impact on the coal industry.

The Department of Energy provided some rough calculations of possible impacts. They find halving CO₂ emissions growth could produce a 25 percent decline in coal industry employment (relative to baseline assumptions) by 2025, while stabilizing emissions could require a 40 percent decline over this 35-year period. Global commitment to a 20 percent emissions cut could lower employment by about half; unilateral OECD commitment to this global goal would eliminate the U.S. coal industry, as would global or OECD-only commitment to a 50 percent reduction in CO₂ emissions.

It is important to recognize, however, that elimination of coal-mining jobs gradually over time does not necessarily imply increased general unemployment, in the case of an expanding economy though there may be persistent regional problems. A shift to other energy sources would create jobs. In the short run, jobs will likely be created in the natural gas industry. In the longer run, three regional studies of biomass energy use sponsored by the Department of Energy's Regional Biomass Energy Program (Council of Great Lakes Governors, 1985; Chamberlin and High (1986); Tennessee Valley Authority, 1989) suggest that a shift from fossil to biomass energy would on balance create jobs. Similarly, a study conducted for the California Energy Commission (1986b) suggests that renewable energy technologies are generally more labor-intensive than oil and gas.

2. Regulatory Adjustments. There are a number of reasons why total U.S. investment in energy-efficiency may be suboptimal. First, many costs associated with the production, transportation, and conversion of fuels--including air and water pollution, storage of nuclear wastes, and reduced energy security--are not fully reflected in retail prices for fuels and electricity. Second, electricity prices tend to be based on average cost rather than on marginal cost, which is often higher. Third, it is often difficult for buyers to acquire or analyze information on available energy efficiency options. It has been argued that this difficulty leads industrial buyers to ignore energy use implications of relatively small purchases--such as lighting. Similarly, since it is difficult to estimate future utility

bills, it has been argued that builders and homeowners tend to focus excessively on the initial capital costs of appliances and space heating systems, rather than on discounted lifecycle costs. At least one often-cited econometric study (Hausman, 1979) finds that, consistent with this hypotheses, consumers act as if they have abnormally high discount rates when making appliance purchase decisions.

Based on these and related arguments, and on studies that suggest that cost-effective conservation could reduce U.S. energy use by 20 percent or more (Pirkey and Scheer, 1988), many analysts have called for a variety of regulatory initiatives to increase the efficiency of energy use and, thereby, to reduce CO₂ emissions.

a. Reform of Electric Utility Ratemaking. It must be understood at the outset that average cost is not always below marginal cost and that electricity prices are not always set by simply averaging costs. The prospect of self-generation by some large industrial customers, in particular, may serve to keep industrial prices near marginal cost.

The literature on this issue is thin, but a recent study by Wenders (1986) provides an instructive empirical analysis of electricity prices charged by 5 major utilities throughout the United States. Using 1980 and 1981 data, he finds that prices were on average below marginal cost, but the pattern of deviations from marginal cost was complex. Prices were above (long-run) marginal cost in peak periods and below marginal cost otherwise; residential prices were below marginal cost, while some utilities charged commercial and industrial customers prices above marginal cost.

This complexity, the likelihood that price elasticities vary by customer class and between peak and off-peak periods, and the variability of rate structures within Wenders' small sample suggests that the elimination of electricity pricing distortions would be as likely to yield increases in consumption and emissions as decreases--though such reform would on balance improve resource allocation.

b. **Utility Demand-Side Management.** Many analysts have called for reform of electric and gas utility regulation to give utilities incentives to remove impediments to efficient investments in energy conservation. The basic rationale is that existing regulation discourages utilities from promoting energy efficiency, because lower demand generally reduces earnings, and that there are information-related entry barriers to third-party providers of "energy services" (Moskovitz, 1988). Two approaches to reform have been widely discussed.

The first approach is to permit utilities to increase their earnings by making cost-effective investments in conservation--even if those investments are on their customers premises. Programs of this sort are newly in place or under development for 8 New England electric utilities, which account for about 75 percent of the region's power demand (Foy, 1989). A key feature of these efforts is close attention to evaluation and monitoring; this should result in a rapid accumulation of useful data. Based on preliminary experience, the Conservation Law Foundation estimates that programs of this sort could reduce annual U.S. anthropogenic CO₂ emissions by between 0.7 and 0.8 percent (Foy 1989, 1990).

A second, complementary approach is to integrate conservation into the competitive bidding process for meeting new electricity supply requirements, which has been adopted in 18 states and is under active consideration in at least 15 more. Cicchetti and Hogan (1989) describe an economically-efficient approach to doing this. The beginnings of such a comprehensive program can be found in such diverse states such as Maine, Massachusetts, New York, California, and Wisconsin. Bidding selection criteria could also include environmental externalities to allow environmentally clean projects to compete favorably with lower cost but less environmentally attractive proposals. A step in this direction has recently been taken in the New York State Energy Plan (1989).

While the desirability of regulatory changes of these sorts is apparent, estimates of potential achievable savings of electricity range from 4 percent to 75 percent. Industry sources such as the Electric Power Research Institute (1989) estimate potential savings of 20 percent between 1977 and 2010. The uncertainty surrounding these estimates is evident from the size of the range. According to the Northwest Power Planning Council, which has extensive experience in demand-side efforts, hard quantifiable experiences is "extremely limited." The New England efforts discussed above may remedy this in a few years.

c. Research and Information. During the past 8 years, DOE's R&D budgets for end-user energy efficiency improvements have declined significantly. DOE's 1989 conservation budget in constant dollars is less than a third of its 1980 level. However, DOE's budget for supply efficiency has increased. As a proportion of the total national energy R&D budget (including expenditures by DOE, NRC, EPRI, and GRI), energy efficiency accounts for only 9 percent. Expanded funding would permit DOE to work more closely with industry to demonstrate new energy-efficient technologies, assess the long-term performance (durability) of energy-efficient technologies, and revive research on the patterns and determinants of energy-related decision making and the barriers to adoption of energy-efficiency actions.

Similarly funding for DOE programs that provide financial and technical assistance to states has decreased by 2/3 in recent years. (These programs include the State Energy Conservation Program, the Energy Extension Service, and a small Least-Cost Utility Planning Program.) There are a number of areas where DOE could sponsor demonstration of energy-efficient equipment and work with trade associations to encourage dealers to stock energy-efficient systems and building managers to install them.

d. Building and Appliance Standards. Experience with energy-efficiency standards throughout the country (especially in California and the Pacific Northwest) shows that they can reduce energy consumption, and thus CO₂

emissions. For example, California's Title 24 building standards cut statewide electricity use by almost 2 percent in 1985 and are expected to cut electricity use by more than 6 percent in 2007 (California Energy Commission 1988). If imposition of Federal standards is deemed inappropriate, DOE could assist state and local governments on code development and training and could assist builders on design and construction techniques aimed at cost-effective conservation. These and related objectives would be furthered by increasing DOE's budget for building standards and guidelines, currently only \$700,000 a year.

The National Appliance Energy Conservation Act of 1987 (U.S. Congress 1987) requires DOE to review appliance efficiency standards on a regular basis and to promulgate more stringent standards where technically and economically feasible. As noted above, the Administration generally prefers incentives or direct correction of market failures to the imposition of command-and-control standards. The pace of the statutorily required review could nonetheless be accelerated. DOE could also review the feasibility of expanding efficiency standards to other products, including incandescent and fluorescent lamps.

e. Transportation. The corporate average fuel economy (CAFE) law was enacted in 1975 and established a fleet-average goal of 27.5 mpg for 1985 and beyond. That goal has been achieved, and the average fuel economy of the new car fleet has been quite stable at around 28 mpg for several years. Increases in fuel economy have produced essentially proportional reductions in CO₂ emissions per vehicle mile. The CAFE program is controversial and was opposed by the previous Administration, though the standard was increased by this Administration in the spring of 1989.

Further increases in the CAFE standard are feasible and would likely reduce CO₂ emissions; estimates of the costs of such increases are controversial. It seems clear that widespread use of currently-available and likely future technologies would permit increases in the average fuel economy of the new car fleet without reducing performance below recent levels. The

Office of Technology Assessment (OTA; Plotkin, 1989) considers standards in the 32-33 mpg range for model year 1995 to be feasible in this sense. The Department of Energy (Stuntz, 1989) point to a 29-31 mpg range for that year, and 36 mpg by 2000. The OTA estimates that by 2010 a 33 mpg standard would reduce U.S. fossil fuel CO₂ emissions by 0.5 percent (and world emissions by 0.1 percent) and U.S. fuel use by 5 percent. Oil imports would also be cut.

The difficulty of assessing the costs and benefits of increases in the CAFE standard was discussed in Section IV.A.3, above. Benefits will be reduced if higher prices than would otherwise obtain reduce new car sales and thus slow the improvement in fleet-average economy. Benefits will also be reduced if lower per-mile costs lead to more miles per car. Cost analysis must also consider impacts on diverse consumers, not just on national averages, and must take into account performance improvements foregone as well as the reductions in safety and spaciousness that could occur if manufacturers meet higher standards in part by downsizing. Since fuel economy labels provide good information, it is not clear that CAFE standards would remedy any market failure that could not be addressed more efficiently by employing a carbon charge or gasoline tax.

f. Agricultural Policy. A number of changes in agricultural programs that would have other benefits can be expected to assist in reducing emissions of greenhouse gases. These include reducing commodity price support levels, encouraging additional tree planting, and conservation cross compliance.

This and the preceding Administration have sought to reduce price support levels for program crops in order to increase the efficiency of resource use within the agricultural sector. Reducing agricultural subsidies will tend to reduce total crop acreage and change the mix of crops grown. Corn and wheat, the two most widely grown program crops, account for 57 percent of nitrogen fertilizers used. As is discussed in Section IV.E, below, the use of these fertilizers is associated with emissions of nitrous oxide (N₂O), a potent greenhouse gas. Reducing income support can be expected to reduce the acreage

devoted to corn and wheat and, possibly, to increase the acreage devoted to soybeans, which fix their own nitrogen from the air. In addition, reducing income support is likely to reduce per-acre use of all inputs, including nitrogen fertilizers (Miranowski et al.).

Reducing agricultural support prices should also slow the rate of conversion of forest and woodlands to cropland. It should also encourage the conversion of marginal cropland into forestland, particularly in areas where commercial forestry opportunities exist. This could result in a significant increase in CO₂ removal from the atmosphere. The key point is that less support would allow farmers to respond to market changes induced by climate change.

Cross compliance (Conservation Compliance) requires farmers who cultivate highly erodible land to have a Soil Conservation Service approved conservation plan by 1990 and to have it fully implemented by 1995. These plans for the most part require the use of conservation tillage, which reduces mechanical soil preparation and mechanical cultivation. Consequently, it reduces the number of tractor passes through the field and the total tractor operating hours per acre. This should result in a significant reduction in CO₂ and N₂O emissions. But it also could mean increased use of herbicides and pesticides, leading to other potential problems.

3. New Technologies. This section considers the role of advanced technology in reducing CO₂ emissions in the electric generation and energy end-use sectors. Of particular interest is how much can be gained by broader use of currently available technologies that enjoy only limited commercial use because they are new and/or expensive, as well as advanced technologies that only require modest additional development for widespread application. While new technologies offer significant CO₂ emissions reduction potential after 2000, there is no simple "technological fix" to this problem. Regulatory barriers may affect the economics and introduction of some technologies.

At any given time, a combination of technological, behavioral, market, regulatory, and macroeconomic factors interact to determine patterns of energy use, the introduction of new technologies into widespread acceptance, and the further deployment of technologies already in use. Even in the analysis of high-quality historical data, it is difficult to identify the portion of actual energy use that is due to any single causal factor, including new technology. Thus the discussion below can only be indicative of the likely role of new technology; further research may well change its conclusions.

Progress in reducing CO₂ emissions depends on installing and using new technologies in a host of applications. Key determinants of the penetration of new technologies are sectoral rates of growth and average economic lifetimes of capital assets. Lifetimes vary considerably, from motor vehicles (8-14 years) to residential (30-80 years) and non-residential (31-48 years) structures. Electric generating equipment (10-55 years), other transportation equipment (16-28 years), and industrial equipment (14-27 years) have intermediate lifetimes. Moreover, it can take years for economical new technologies to become accepted. Thus new energy technologies may not come into widespread use even in new installations for years--or even a decade or more--after they are commercially available.

a. Electricity Generation. By 2010 an estimated 400 gigawatts (GW) of new electric generating capacity may be needed to meet demand increases and to replace existing capacity that will retire. New technologies can, therefore, play a significant role in limiting CO₂ emissions from new electric generating sources. But it must be recognized that only 65 GW of this total will replace retired capacity; about 655 GW (91 percent) of existing capacity will not retire until after 2010. CO₂ emissions may also be reduced as existing generating units are repowered and reboilered with more efficient technologies or with equipment designed to burn fuels with lower carbon content.

A variety of new technologies that produce electricity from coal, oil, natural gas, and methane with improved efficiency in the conversion of fossil

energy into electrical energy are in various stages of development. By reducing the amount of fossil fuel burned to generate a given amount of electricity, these technologies can reduce CO₂ emissions per unit of electricity produced. Renewable resources, primarily hydropower and wood, provided 8 percent of the nation's energy in 1988. Newer renewable resource technologies, including wind, solar thermal electric, geothermal electric, photovoltaic, and biomass technologies, will make increasing contributions in coming decades.

The future use of nuclear power both worldwide and in the United States is and will be dependent upon many factors, including relative cost, national security considerations, third world development, progress in dealing with nuclear waste disposal and nuclear weapons proliferation, continued safe operation of existing nuclear plants, and establishment of a stable and certain licensing process. The goal of the DOE nuclear reactor program is to develop nuclear reactors with simplified and standardized designs and passive safety features, designs which hold the promise of revitalizing the nuclear power industry through the simplification of the licensing process and resulting reduction in costs and financial risks. In addition, an NRC rulemaking procedure is in place to pre-approve standardized nuclear plant designs so that parties interested in purchasing a plant have assurance that there will be no intractable licensing problems. Final designs will be ready for demonstration or commercialization in the 1990s and, if public attitudes and regulatory changes reduce business risks, the next generation of reactors may come into use after 2000.

On balance, while important gains in generation efficiency are possible, they are not likely to penetrate the market substantially in the near term based on market forces alone. The potential for advanced technology to reduce generation-related CO₂ emissions appears to increase substantially after 2000, but this potential has wide uncertainty bounds.

It is technically possible to "scrub" carbon from combustion waste gases, but it is very expensive. One study concludes that collection and disposal of powerplant CO₂ emissions would at least double the cost of coal-fired electric power (Steinberg, 1983). There has also been some discussion of methods of utilizing only the hydrogen in fossil fuels (Steinberg and Cheng, 1987). These ideas are in their infancy and are many years away from commercial application.

b. Energy End-Use Technologies. Many estimates of conservation potential indicate that new technologies could produce significant savings over expected energy use, even by the year 2000. These estimates are buttressed by analysis of historical data, which indicates that over the 1972-86 period, technology improvements have played particularly significant roles in reducing energy use in all sectors, particularly industrial and transportation but also including commercial and residential buildings.

The contributions from new technology to energy efficiency gains are potentially substantial, particularly after 2010. Of course, the eventual levels of application depend heavily on fuel prices and the economic lifetimes of capital stock. Because of lower lifetimes, the prospects for near term stock turnover are highest for transportation vehicles, appliances, and some light industrial equipment. Most residential, commercial, industrial and utility structures and large equipment technologies require much longer time periods to be replaced.

On balance, advanced energy use technology seems to have the potential to contribute significantly to reducing CO₂ emissions, but estimates of the extent of the contribution vary widely. Most energy projections indicate that energy efficiency gains on the order of 12 percent can occur by 2010 through the operation of market forces if fuel prices rise as projected. Substantial additional gains in energy efficiency could occur by application of "best-practice" technology, but extensive policy interventions or much higher fuel prices are essential to achieve them. Most studies have found that the potential gains from widespread use of available "best practice" technology

are significant. Significant technical potential for efficiency improvements and fuel switching beyond 2010 exist, but increased efforts to develop and commercialize new technology are required in the near term to achieve these gains.

4. Forestation. Reforestation and afforestation policies may remove CO₂ from the atmosphere and store the carbon in the woody parts of living trees. By preventing the release of such carbon, policies that limit deforestation reduce net emissions of CO₂. However, reforestation may affect microclimates and the soil's ability to absorb CO₂. As a forest grows, an annual flow of carbon is removed, but it is generally assumed that carbon release from decay balances carbon uptake from new growth in mature forests. Reforestation is a (comparatively) short-term approach that may cause a substantial decrease in net CO₂ emissions for three to five decades (Sedjo and Solomon, 1988). After this period, a large effort would be required to keep the absorbed carbon sequestered. However this delay could allow time for the development and adoption of new technologies that emitted less carbon, or the mature timber could substitute for fossil fuels creating a closed carbon cycle with continuous replanting.

a. Cost Analysis. Sedjo and Solomon (1988) provide cost estimates for a global reforestation plan designed to sequester the entire flow of net additions of carbon to the atmosphere. Carbon absorption is highest for recently planted fast growing species on tropical sites. Plantations with these characteristics are estimated to sequester 2.3 metric tons of carbon annually per acre. If such sites were used, an estimated 1.1 trillion acres of land would be required, while if slower growing trees were planted on sites in temperate zones, over 7.4 trillion acres would be required. These are large requirements; 1.1 trillion acres is 50 percent greater than the current forested area in the United States and more than 15 percent of the forested areas in the world. A forestation program on this scale would require a worldwide search for suitable and inexpensive land.

Estimated total costs of absorbing global net carbon emissions range from \$372 to \$697 billion. Based on total program costs and assuming a 30 year rotation, the cost ranges from \$4.29 to \$8.03 per metric ton of carbon removed. In addition, future harvest of the large quantity of trees required for significant carbon sequestering could disrupt timber markets and dramatically reduce incentives for planting on private forestland.

Moulton and Richards (1989) examine a more modest carbon sequestering program in the United States. They conclude that marginal costs per ton range from \$17.71 to \$102.63 per metric ton depending on program size. The lower estimated per ton costs for the larger worldwide sequestering program flow from more optimistic assumptions about both carbon absorption and land costs. These assumptions may be justified on the availability of less expensive land outside the United States and faster forest growth rates on tropical sites. However, the smaller program with more pessimistic assumptions is probably a more reliable guide to costs for U.S. reforestation programs.

Forestation programs of moderate size can be implemented in a wide variety of ways to minimize impacts on land costs. Several options have been outlined by the U.S. Forest Service (1989), including volunteer urban tree planting programs, cost-sharing and technical assistance programs, and land leasing programs. For example, enhancing forest growth on sparsely forested land would not increase competition for land but would increase carbon uptake. Urban tree planting would not raise land costs and, by providing shade, may reduce fossil fuel consumption by reducing demand for air conditioning. Land leasing forestation programs or programs that only involve cost sharing in the costs of planting, improving, and managing lands for timber production are two alternatives for increasing forestation on private non-urban land. On a large scale, such programs could reduce expected stumpage prices and thus lead to reduced forestation in current commercial forests.

The net ecological and recreational benefits of forestation would depend on the type of forest planted and the current use of the land. All types of

forest would tend to have soil erosion benefits when established on erodible cropland. However, fast growth forest plantations, with repeated harvest of small trees for fiber or energy, would have few recreational benefits and offer habitat for limited species of wildlife. Frequent harvests and replanting of fast growth stands might result in added erosion if such forests replaced natural forest land or grasslands. Grassland, sparse forest land, mixed use forest (including grazing use), and old growth forests offer diverse and unique wildlife habitats and ecosystems. Since the greatest intake of CO₂ occurs in young, fast-growing stands, enhancing the carbon storage properties of land in such current uses would dramatically change the ecosystem, and widespread forestation with the sole goal of carbon storage could significantly decrease biodiversity.

b. Management. Because new forests represent a growing stock of carbon, the efficacy of forestation as a carbon management tool depends importantly on how the stock of accumulated carbon in mature forests is managed. If new forests are allowed to mature, significant carbon removal would occur only over a 30 to 40 year period. To continue carbon removal through forestation would require forest establishment on increasingly large areas of the Earth's surface.

If forest land is cleared for other uses in the future, the carbon stored during forest growth is then released to the atmosphere. If forest carbon is somehow stored so that decay and release to the atmosphere does not occur, a continuous flow of carbon can be removed. (Solidwood products are estimated to contain only about 0.5 percent of the carbon in living trees, however (Rotty, 1986).) More plausibly, forests might be used as an energy source. In this case, net carbon removal would occur while new forest growth is established, and a continuing carbon reduction benefit would occur to the extent that bio-fuels replaced fossil fuels.

Each of these management options has quite different effects on economic cost and on carbon removal. Unfortunately, the costs and carbon removal benefits of these options have not been systematically analyzed.

C. Methane

Methane (CH₄) accounted for about 19 percent of the increase in radiative forcing in the 1980s. The rise in atmospheric CH₄ concentrations over the last century is due to a relatively small imbalance between sources and sinks. Current assessments indicate that atmospheric stabilization will require only a 10 to 20 percent reduction in annual emissions.

As Table II.3 showed, the developed countries account for only about 25 percent of anthropogenic CH₄ emissions, in part because over half these emissions are produced in agriculture. Thus significant, cost-effective reductions in CH₄ emissions will require global action. While a number of approaches to controlling these emissions are available, no systematic policy design or costing analysis seems to have been performed. There are ongoing efforts within the Administration to better quantify the costs of methane reductions and to develop, refine, and demonstrate best management practices within the areas discussed below: animal waste, coal mining, landfills, livestock, and rice.

1. Animal Waste. Animal wastes are estimated to generate about 4 percent of anthropogenic CH₄ emissions. This occurs largely in developed countries where these wastes are managed in lagoons. The most promising technology for abatement of this methane is decomposition in anaerobic digesters to produce methane gas, which, like natural gas, can be used to produce electricity and/or shaft power or be burned in boilers as a heat source. This approach is most promising at sites with large animal herds such as feedlots and dairy farms. Full recovery at these sites would reduce these emissions by over 50 percent. USDA estimated in 1978 that approximately 50 million tons of "economically collectable" livestock and poultry residue, when converted through anaerobic digestion, could generate CH₄ equal to 7 percent of the natural gas consumed in the United States in 1988.

Fewer than 100 anaerobic digesters currently are operating on farms in the United States, however. Most of these are producing electricity to power farm equipment. Excess electricity often is sold to the utility grid system. Poor economics, management problems and infrastructural barriers have restricted widespread adoption of this technology. Most of the plants are one of a kind and expensive. Typical costs of electricity generated are 5 to 7 cents per kwh. Additional research should enable the development of standardized facilities that are substantially cheaper and more efficient. Currently, farmers receive 2 to 3 cents per kwh for electricity they provide to utilities except in a few areas, notably California where 9 to 11 cents per kwh is paid. Many power companies are reluctant to accept power from farmers, and establish major road blocks adding to the cost of an intertie.

2. Coal Mining. Methane from coal mining is estimated to contribute 13 percent of anthropogenic emissions. This methane is pipeline quality and can be recovered as a resource, thereby both reducing CH₄ emissions and use of other fossil fuels. It is technically feasible to reduce 60 percent of these methane emissions through pre-mining degasification. This recovery would be performed at a limited number of sites, since about 10 percent of the world's mines generate most of the methane. These mines are concentrated in the 9 countries that produce the bulk of the world's coal.

Economic assessments show that methane recovery can be profitable with existing technology. Indeed, several recovery operations are running profitably in the United States. An important limitation to more recovery in the United States is that gas companies typically own the rights to the methane in coal mines. The coal companies can only profit from methane recovery by buying rights to this methane or setting up some sort of joint venture operation.

Preliminary assessments also show that mining methane could be profitable in countries such as China and Poland. For example, analysis suggests that it is less expensive for China to derive BTUs from mining methane than coal.

Much of China's coal is deep mine coal that is expensive to bring to the surface, and gas pipelines are less expensive to build than the railroads necessary to transport the coal. Despite these analyses, methane mining has not been implemented on a large scale, and a continued rise in coal mining activity is planned to meet China's growing energy needs. Since the USSR, China, East Germany, and Poland are major coal producers, transfer of methane recovery and methane mining technologies to these countries could produce substantial benefits.

3. Landfills. Landfills, mainly in developed countries, are estimated to contribute 10 percent of anthropogenic CH₄ emissions. Of the 6,584 municipal solid waste landfills in the United States, only 123 (1.9 percent) now recover methane for energy use. Under current market conditions, methane recovery is only viable for large sites with a suitable gas user nearby or at which electricity can be generated and sold into the grid. Regulatory barriers also exist in many areas. Ongoing research aims at enhancing the economic viability of methane recovery.

EPA hopes to promulgate regulations limiting CH₄ emissions from large landfills in the United States. EPA believes that these regulations have the potential to reduce total anthropogenic CH₄ emissions by about 1.5 percent. Controls applied in other countries could produce further reductions.

4. Livestock. Livestock generate about 20 percent of anthropogenic CH₄ emissions. Intensive (grain-fed) animal production systems used in developed countries result in significantly less methane per unit of output than do extensive (grass-fed) systems prevalent in developing countries. Production methods that enhance efficiency of livestock enterprises also reduce methane emissions per unit of output. Through changes in diet and management of smaller herds due to increased productivity, emissions may be reduced by 25 to 75 percent. Other options for methane reduction include increased use of hormones and lower price supports. The costs of these changes will be small.

In developing countries, many of the cattle are nutrient-deficient. By supplying nutrient supplements, methane emissions can be reduced, but the costs and potential of this approach are not well understood. In general, while it is possible to reduce methane emissions from intensive livestock production systems, relative gains will be small and may not be achieved without significant technological advance. Further development of best-practice livestock management systems and diffusion of those systems into practice seem the most promising steps in this area.

5. Rice. Rice cultivation accounts for about 34 percent of anthropogenic CH₄ emissions. Recent work shows that methane emissions may be reduced by decreasing use of animal manures as fertilizer, but there is still considerable uncertainty regarding the cost and volume of reductions that can be achieved in this manner.

D. CFCs and Related Substances

Chlorofluorocarbons (CFCs) accounted for about 14 percent of increased radiative forcing in the 1980s. In the absence of any control measures, CFCs would account for a much larger share of future increases. However, the Montreal Protocol on Substances that Deplete the Ozone Layer represents a commitment to significant controls. While primarily aimed at limiting CFCs and halons because of the threat they pose to the ozone layer, this treaty also results in substantial benefits in terms of global warming. The Montreal Protocol has now been ratified by 49 nations and the European Community. These nations account for over 90 percent of the global consumption of CFCs.

In response to recent scientific evidence that the risks of ozone depletion from CFCs and other ozone-depleting substances are greater than previously thought, President Bush and others have called for strengthening the Protocol by phasing out CFCs and halons completely. Over 70 nations supported the Helsinki Declaration at the first meeting of the Parties to the Montreal Protocol in May 1989, which calls for a phase-out of CFCs and halons

and limits on other ozone-depleting chemicals. The Protocol will be renegotiated in June 1990 and will almost certainly include a phase-out of all CFCs by the year 2000 for applications where there are safe substitutes plus major reductions in halon use. This phase-out would significantly reduce the increase in radiative forcing in the next century.

Significant technological advances made during the past several years make such a phase-out feasible. In the near term, substantial emission reductions are being achieved through increased recycling and improved housekeeping (particularly by electronics companies in their use of CFC-113). Development of chemical and process substitutes has also progressed rapidly and has allowed major firms and industries to establish goals for eliminating their use of CFCs ahead of the likely Montreal Protocol schedule. For example, IBM and AT&T have a phase-out goal by 1994 and the electronics industry as a whole, through its major trade association, has established the goal of an 80 percent reduction by 1997 and a phase-out by 2000. Similarly, the rigid foam insulation industry has established a goal of a complete phase-out by 1995.

The costs of eliminating the use of CFCs and halons will be approximately \$3 billion over the next ten years (1989 dollars, discounted at 5 percent). These costs could be substantially reduced, along with CO₂ emissions, if industry can move to more energy efficient refrigerants. For example, if the use of HFC-152a as a refrigerant proves acceptable, cost savings from improved energy efficiency could reduce the costs of a phase-out in these applications by 57 percent over the next ten years. EPA and other agencies are working with several industry groups to examine technological, environmental, and institutional issues related to the use of a wide array of more energy efficient, low greenhouse alternatives.

E. Nitrous Oxide

Nitrous Oxide (N₂O) accounted for about 5 percent of the increase in radiative forcing in the 1980s. As Section II noted, data on sources of N₂O emissions are quite poor. The primary anthropogenic source seems to be the use of nitrogenous fertilizers, which is increasing at 1.3 percent per year in industrialized countries and 4.1 percent per year in developing nations.

From the point of view of policy design, it is unfortunate that the nitrogen content of fertilizer is not the primary determinant of N₂O emissions. Emissions of N₂O vary by one to two orders of magnitude among different types of nitrogenous fertilizers. Other factors affecting emissions include the rate and timing of fertilizer application, the placement of fertilizer (deep or shallow), water management (particularly in rice cultivation), tillage and herbicide use, and the use of legumes as a nitrogen source. No systematic attention seems to have been devoted to the design or cost of policies to reduce N₂O emissions from fertilizer use or other sources, in part because the relevant science base is weak, though some of the agricultural policy changes discussed in Section IV.B.2.g., above, would likely reduce N₂O emissions from U.S. farms.

New technologies that improve fertilization efficiency also tend to reduce N₂O emissions, but little appears to be known about their cost-effectiveness. Advances in biotechnology, particularly the development of weed-resistant crop varieties and nitrogen-fixing cereal crops, may reduce N₂O emissions in the future.

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TASK FORCE MEMBERS

Richard Schmalensee, Chairman
Council of Economic Advisers

Bruce Bartlett
Department of the Treasury

Frederick M. Bernthal
Department of State

Robert W. Corell
National Science Foundation

J. Clarence Davies
Environmental Protection Agency

Bruce Gardner
Department of Agriculture

Robert E. Grady
Office of Management and Budget

C. Boyden Gray
Council to the President

Nancy Maloley
Office of Policy Development

Nancy Maynard
Office of Science and Technology Policy

Barry McBee
Office of Cabinet Affairs

Mark Plant
Department of Commerce

John Schrote
Department of the Interior

Linda Stuntz
Department of Energy

THE WHITE HOUSE

WASHINGTON

March 29, 1990

MEMORANDUM FOR D. ALLAN BROMLEY
STEPHEN DANZANSKY

FROM: KENNETH P. YALE

SUBJECT: Framework Convention Negotiations

I have just reviewed the agenda for tomorrow's Global Change Working Group meeting, and would like to bring to your attention some materials related to one of the topics on the agenda.

Attached is a memorandum outlining a proposed approach to begin informal negotiations that will lead to the formal negotiations which the President offered to host. I trust you have reviewed this already. The outline suggests engaging Dr. Tolba to reach an early agreement on the timing and organization of the framework convention negotiations. It also suggests formal negotiations begin in early October, shortly after the IPCC's first assessment report is adopted in August.

I would suggest that this is an extremely short timeframe. If it is to be pursued, then a great deal of work must be accomplished -- even before the August meeting of the IPCC. The question of whether this is too short a time to make adequate and informed decisions on the framework may need to be addressed. In addition, you will recall that the President committed to:

"Hosting a conference next Fall to negotiate a framework treaty on global climate change, after the working groups of the UN-sponsored Intergovernmental Panel on Climate Change submit their final report."

The language was left very general, to maintain flexibility on the actual timing of the first negotiating session. It has been suggested that one month after the final reports are submitted is too short a time period to adequately prepare for negotiations. Moreover, as indicated in the attached memo and observed by several members of the working group, if negotiations follow too soon after the reports, then preparations for the negotiations will become the major focus, overshadowing all other work and deliberations on the science, effects, and response reports. This argues for a careful, deliberative approach to the timing of the first negotiation sessions, in order not to box ourselves in.

cc: Barry McBee



United States Department of State

*Assistant Secretary of State for Oceans and
International Environmental and Scientific Affairs*

Washington, D.C. 20520

March 9, 1990

TO: AID - Eugene Chiavaroli(647-3028)
CEA - Richard Schmalensee(395 6947)
CEQ - John Cohnsen(395-3928)
DOA - Charles Hess(755-7842)
DOC/NOAA - John Knauss(377-8203)
DOC/NWS - Joe Friday(427-2610)
DOE - John Easton(586-1180)
DOI - John Schrote(343-5048)
DOJ - Richard B. Stewart(786-4215)
DOT - Jeffrey N. Shane(366-7127)
EPA - Terry Davies(252-0275)
NASA - Lennard Fisk(426-0754)
NSF - Felice Levine(357-7745)
OMB - Robert E. Grady(395-5730)
OSTP - Nancy Maynard(395-3719)
USTR - Robert Reinstein(395-3911)
Army Corps - Morgan Rees(697-3366)
Treasury - Michael Springer(566-8066)

FROM: DOS/OES - Frederick M. Bernthal

SUBJECT: Preparations for Negotiations on a Framework
Convention on Climate Change

The framework convention issue is now being addressed in several fora. These include the IPCC, UNEP and WHO (whose directors have a mandate to "begin preparations for negotiations"), and there are proposals to address the issue at the U.N. General Assembly (UNGA) which will reconvene in mid-September, and the Second World Climate Conference (SWCC), which will take place October 29 - November 7, 1990.

President Bush has offered to host the opening round of formal negotiations in the United States this fall. We believe that such negotiations should be conducted by senior policy-level representatives with access to central policy circles in their respective capitals. These representatives could, of course, delegate to technical experts defined work within the negotiating process, but such organizational decisions are a policy-level prerogative.

-2-

We understand that UNEP Director Tolba is proposing that an ad hoc, informal UNEP/WMO technical/legal working group meet in early October to begin preparations for negotiations. This group would report on its work to the UNGA and the SWCC. The focus for preparations would remain with the UNEP/WMO group, but both the UNGA and the SWCC would be expected to provide this group with additional guidance on the negotiating process and goals towards which the negotiators should work. The technical/legal group would essentially negotiate the convention, which would then be endorsed by senior policy officials with plenipotentiary powers at the appropriate time. Dr. Tolba's proposed procedure is very similar to the process used to negotiate the Montreal Protocol and the Basel Convention.

The U.S. needs to engage Dr. Tolba on this issue and reach an early agreement on the questions of timing and organization of the framework convention negotiations. These issues have already been discussed informally within the Administration and Dr. Tolba has been approached on the point.

Therefore, with interagency concurrence, I would propose that the U.S. now press for Dr. Tolba's agreement that formal negotiations on the framework convention be initiated in the United States at a senior policy level in early October, after the IPCC's First Assessment Report is adopted by the IPCC Fourth Plenary in late August. Preparations for the opening round of negotiations could be undertaken by a UNEP/WMO technical group in mid-summer, after the adoption of the ASWG report. We expect that report to contain the IPCC's carefully worked out ideas on possible elements for a framework convention and the issues which will likely arise during the negotiations.

I shall assume that you concur in this general approach unless comments to the contrary are received by COB, Monday, March 12. If you should have any comments, please fax them to me at: 647-5947.

THE WHITE HOUSE
WASHINGTON

*Global Change
wk g jr*

May 2, 1990

MEMORANDUM FOR GOVERNOR SUNUNU

FROM: DAVID Q. BATES

SUBJECT: Delegation to Bergen Conference

The issue of the composition of the U.S. delegation to the Bergen Conference on Action for a Common Future, to be held in Norway from May 14-16, has been considered by an interagency strategy task force comprised of members of the Global Change Working Group and chaired by Allan Bromley. The task force concluded that mid-level sub-ministerial representation would be most appropriate in order to avoid some of the problems encountered at last year's meeting in Noordwijk. This would also emphasize U.S. support for the IPCC as the sole viable forum for global change discussions and demonstrate U.S. dissatisfaction with the proliferation of international conferences on the subject. The conclusion of the task force was considered further by the agencies involved in its deliberations, including State and EPA, and endorsed. This position was reached even in light of the fact that many of the other nations attending the conference will be represented by ministerial-level officials (as is evidenced by the attached preliminary attendance list).

Based on the conclusions of the task force and the agencies, State has prepared a tentative delegation list, which is also attached. You will note that no head of delegation is shown on that list. This issue was discussed at yesterday's environment policy breakfast and a consensus view was reached that Dr. John Knauss, the Administrator of the National Oceanic and Atmospheric Administration, would be an ideal head of delegation. His leadership not only fulfills the goal of having an appropriate level official head the delegation, but his scientific background and forcefulness in asserting the need for better science on global change issues sends a strong signal of the U.S. position in this area.

Rev. 29.04.90
se-ministre

THE BERGEN CONFERENCE: MINISTERIAL PARTICIPATION AS OF 29 APRIL
(EXCEPT NORWAY)

<u>Country</u>	<u>Name</u>	<u>Title</u>
Albania	Mr. Farudin HOXHA	(Min. pres la Presidence du Conseil des Ministres)
Belgium	Mrs. Miet SMET	(Min. Env.)
Bulgaria	Mr. Alexander ALEXANDROS	(Min. Env.)
Byelorussian SSR	Mr. KOZLOV	(State Min.Env.)
Canada	Mr. Lucien BOUCHARD	(Min. Env.)
Cyprus	Mr. Andreas GAVRIELIDES	(Min. Agriculture & Nat. Resourc)
Czechoslovakia	Mr. Bedrich MOLDAN	(Min. Env.)
Denmark	Ms. Lone DYBKJER	(Min. Env.)
DDR	Prof. Dr. Karl STEINBERG	(Min. Env.)
Finland	Mr. Kaj-Ole BARLUND Ilkka Suominen?	(Min. Env.) (Min. Handel/industri)
France	Mr. Brice LALONDE (by phone)	(Min. Env.)
FRD	Prof. Dr. Klaus TOPFER	(Min. Env.)
Iceland	Mr. Steingrimur HERMANNSON Mr. Julius SOLNES	(Prime Minister) (Min. Env.)
Ireland	Mr. Pdraig FLYNN, T.D.	(Min. Env.)
Italy	Mr. Giorgio RUFFOLO Mr. Adolfo BATTAGLIA	(Min. Env.) (Min. Industry)
Luxemburg	Mr. Alex BODRY	(Min. Env.)
Malta	Mr. H. M. BONNICI	(Min. Env.)
Netherlands	Mr. Johannes G.M. ALDERS	(Min. Env.)
Poland	Mr. Bronislaw KAMINSKI	(Min. Env.)
Portugal	Mr. Fernando Ferreira REAL	(Min. Env.)
Romania	Mr. Simion HAMCU	(Min. Env.)
Spain	Mr. J.L. Saenz de COSCULLUELA	(Min. Env.)

Sweden	Ms. Birgitta DAHL	(Min. Env.)
Switzerland	Mr. F. COTTI	(Min. Env.)
Turkey	Mr. Vehbi DINCERLER	(Min. Env.)
UK	Mr. Chris PATTEN	(Min. Env.)
Ukraine	Mr. Victor L. FILONENKO	(State Min.Env.)
USSR	Mr. V. Kh. DOGUTIEV	(Vice-Prime Minister Chairman Commission for Natural Disasters)
	Mr. N.N. VORONTSOV	(Min. Env.)
Yugoslavia	Mr. Bozo MARENDIC	(Min. Env.)
	Mr. S. SANTO	(Min. Energy/Industry)
Commission of the European Community	Mr. Carlo RIPA DI MEANA	(Commissioner for Env.)
<u>Observers/Special guests</u>		
Australia	Ms. Susan LENEHAN	(State Min.Env) South Australia)
Brazil	Mr. Jose Antonio LUTZENBERGER	(State Sec.Env)
AMCEN	Mr. J.J. NYAGAH	(Min. Env.Kenya/ President of AMCEN)
AMCEN	Mr. Antonio NDALAMA	(Min. Env. Zambia/ Vice-President AMCEN)

*AMCEN=African Ministerial Congress on Environment

April 30, 1990

TO: Stephen Danzansky
Assistant to the President

FROM: Christine Dawson
Department of State

SUBJECT: USG Delegation to Bergen Environment Conference

Per your request, attached is a list of appropriate agency representatives who have expressed an interest in attending.

1. U.S. Representative - To be determined
2. Ambassador Loret Miller Ruppe
American Ambassador, Oslo
3. John J. Easton, Jr.
Assistant Secretary for International Affairs
Department of Energy
4. Timothy B. Atkeson
Assistant Administrator for International Affairs
Environmental Protection Agency
5. Mark W. Plant
Deputy Under Secretary for Economic Affairs
Department of Commerce
6. Richard Smith
Deputy Assistant Secretary of State
for the Environment, Acting
Department of State
7. Christine Dawson
Policy Planning Staff, Office of the Secretary
Department of State

8. Charles O. Cecil
Deputy Office Director, Office of Ecology, Health and
Conservation.
Department of State
9. John Cohrssen
Senior Advisor to the Chairman
Council on Environmental Quality
10. Laurence S. Campbell
Regulatory Economist
Office of Business Affairs
Department of Commerce
11. Edward Williams
Office of Environmental Analysis
Department of Energy
12. Larry L. Memmott
Economic Officer
American Embassy, Oslo

Satellite warming
25% measuring carbon

Paul Browning

GREENHOUSE GAS EMISSIONS

TRENDS AND POLICY OPTIONS

Paul Browning
file

MAY 30, 1990

GOALS OF BRIEFING

(1) REPORT ON COMPREHENSIVE APPROACH (15% ISSUE)

- ASSESS WHERE WE WILL BE IN FUTURE GIVEN CURRENT COMMITMENTS, BOLSTERED BY BUSH ADMINISTRATION INITIATIVES
 - ASSESS WHERE WE WOULD HAVE BEEN WITHOUT CURRENT COMMITMENTS
 - ANALYSIS REVEALS EMISSIONS REDUCTIONS EXCEED 15% ESTIMATE
-

(2) ASSESS POLICY IMPLICATIONS OF EMISSIONS PROJECTIONS

- COMPREHENSIVE ASSESSMENT APPROACH REVEALS THAT ADDITIONAL POLICY INITIATIVES MAY STABILIZE OVERALL GREENHOUSE GAS BUDGET

GREENHOUSE GAS INVENTORY

0 GREENHOUSE GASES:

CARBON DIOXIDE (CO_2)

METHANE (CH_4)

CHLOROFLUOROCARBONS (CFCs)

NITROUS OXIDES (N_2O)

TROPOSPHERIC OZONE (O_3)

0 GASES THAT AFFECT CONCENTRATIONS OF GREENHOUSE GASES:

VOLATILE ORGANIC COMPOUNDS (VOCs)

CARBON MONOXIDE (CO)

NITROGEN OXIDES (NO_x)

0 PROBLEM: NEED WAY TO TRANSLATE VARIOUS GASES INTO A COMMON CURRENCY

12/6 Account.

GASES DIFFER IN ATMOSPHERIC LIFETIMES AND POTENCY

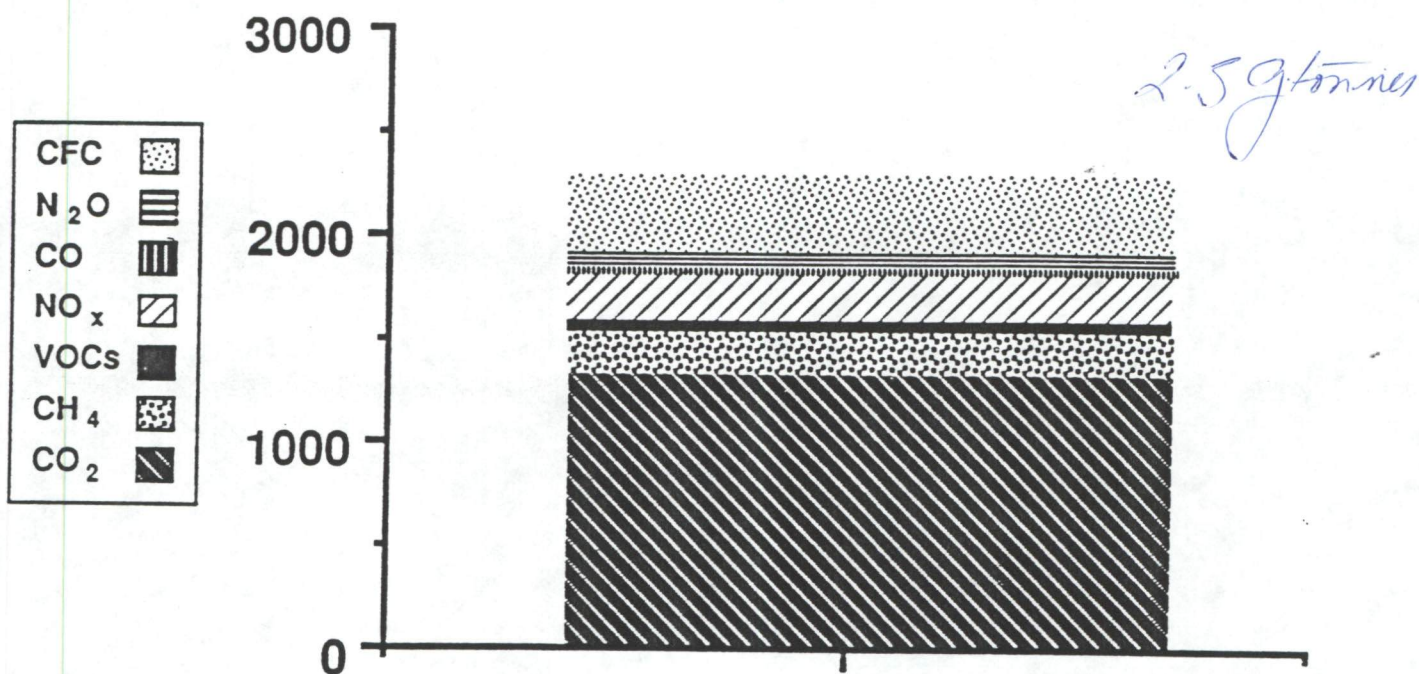
- o OVER THE VERY LONG TERM, CO₂ IS MOST IMPORTANT BECAUSE OF ITS LARGE ATMOSPHERIC CONCENTRATION AND LONG LIFETIME.
- o HOWEVER, IN THE NEAR TERM, METHANE, TROPOSPHERIC OZONE, AND GASES THAT CONTRIBUTE TO THE FORMATION OF GREENHOUSE GASES (e.g., CO, NO_x, VOCs) HAVE LARGE IMPACTS.

GAS	LIFETIME (years)	INSTANTANEOUS RADIATIVE FORCING (relative to CO ₂)	POTENCY OVER 20 YEARS (relative to CO ₂)	POTENCY OVER 100 YEARS (relative to CO ₂)
CO ₂	120	1	1	1
METHANE	10	58	63	21
CFCs	7-200	1640-5800	1500-7100	430-7300
NITROUS OXIDES	150	206	270	290
OZONE	1	1600	207	57

SOURCE: IPCC draft Science Report

U.S. Current Emissions 1987

Carbon Equivalents – Millions of Tonnes



	1987
CO ₂	1310
CH ₄	234
VOCs	52
NO _x	218
CO	52
N ₂ O	74
CFC	367
Total	2308

g-tonnes

CURRENT EMISSIONS REDUCTIONS TRENDS BOLSTERED BY BUSH ADMINISTRATION INITIATIVES

CURRENT COMMITMENTS	MILLIONS OF TONNES REDUCED (Carbon Equivalents) 2000
0 TREE INITIATIVE (1 Billion Trees per Year)	9
0 DOE INITIATIVES (Efficient Lighting, Building Standards, LCUP, Energy Audits, Expanded Hydro)	34
0 DOE APPLIANCE STANDARDS (Refrigerator/Freezer, Washer, Dryer, Dishwasher)	4
0 CLEAN AIR ACT	62
0 LANDFILL REGULATION (EPA proposal) [Southeast]	44
0 CFC PHASEOUT & MONTREAL PROTOCOL	551
702 ± 200	

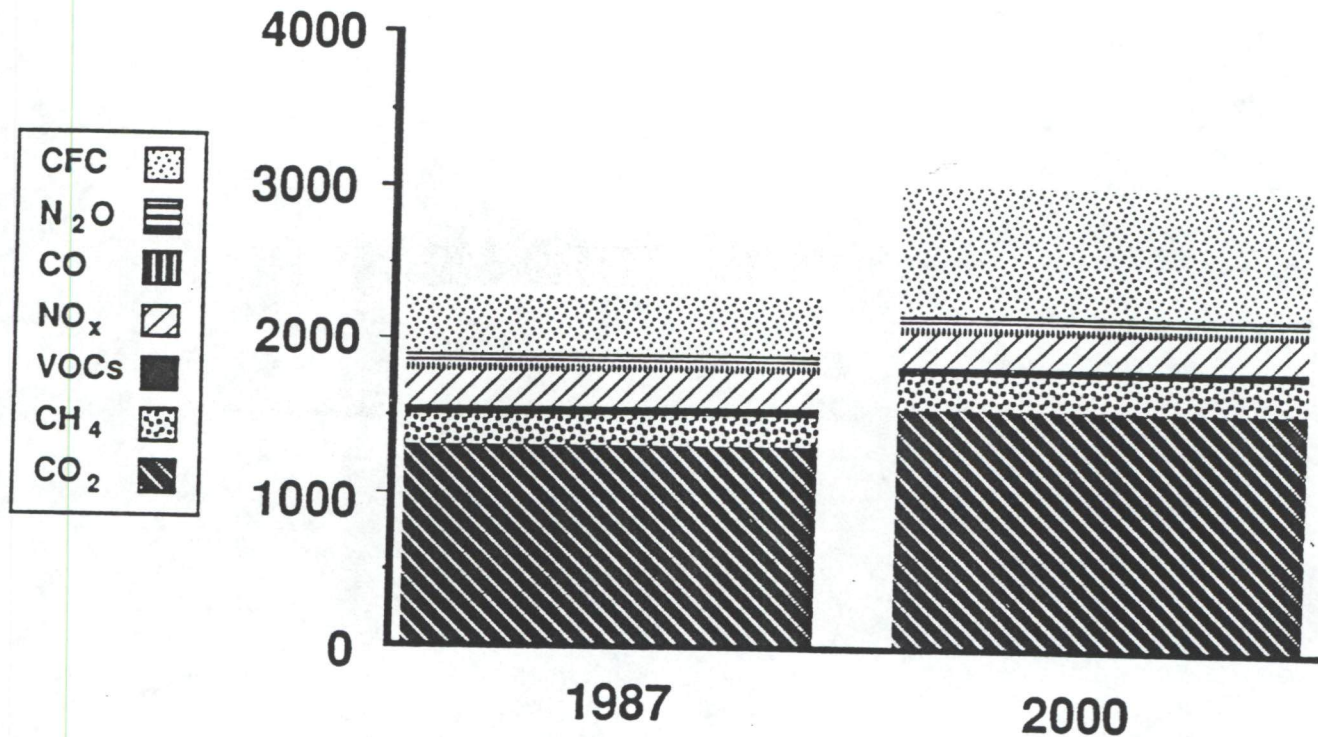
1/4 EDF → number.
tropospheric ozone dominant carbon monoxide too.
more than half

Business as Usual

U.S. Emissions

(Without Current Commitments)

Carbon Equivalents – Millions of Tonnes



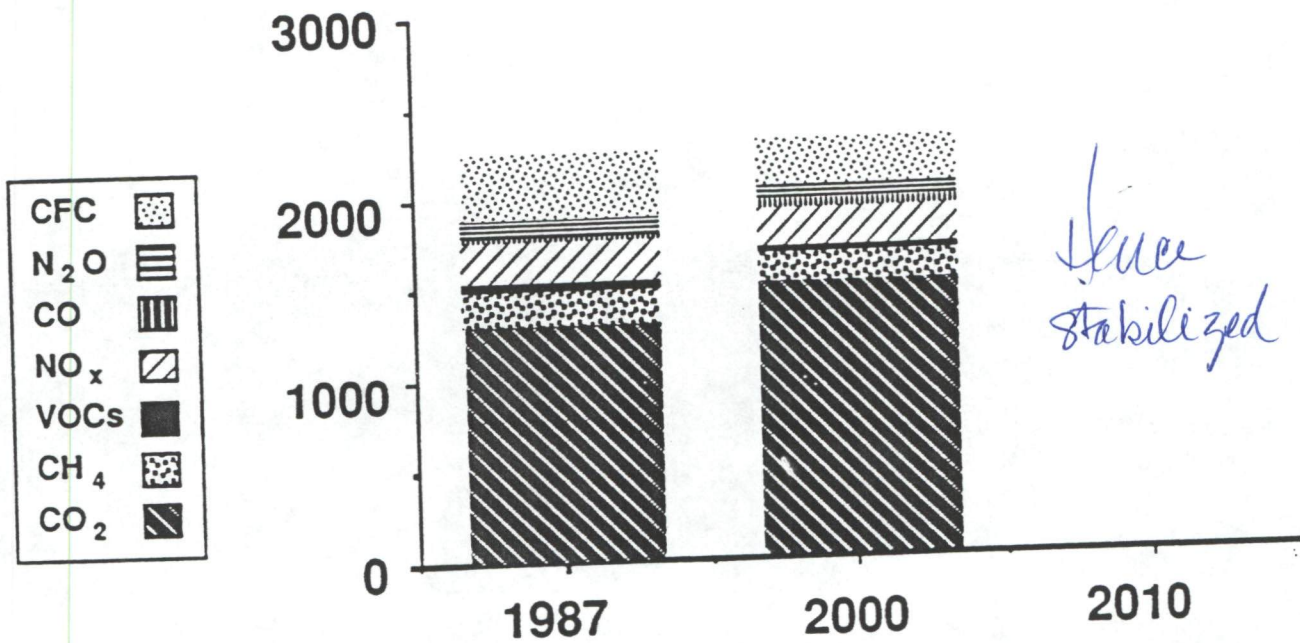
	1987	2000
CO ₂	1310	1565
CH ₄	234	252
VOCs	52	52
NO _x	218	218
CO	52	52
N ₂ O	74	74
CFC	367	807
Total	2308	3020

NOTE: ASSUMES 100 YEAR GWP FACTOR

Emissions

(With Current Commitments)

Carbon Equivalents – Millions of Tonnes



	1987	2000	2010
CO ₂	1310	1502	
CH ₄	234	208	
VOCs	52	35	
NO _x	218	199	
CO	52	45	
N ₂ O	74	74	
CFC	367	256	
Total	2308	2318	

In Progress

COMPREHENSIVE EMISSIONS REDUCTIONS EXCEED 15% ESTIMATE

- o ANALYSIS REVEALS THAT CURRENT COMMITMENTS,
BOLSTERED BY BUSH ADMINISTRATION INITIATIVES,
YIELDS A 24% EMISSIONS REDUCTION**

TRANSPORTATION TAXES

FOR THE YEAR 2000

(all numbers in constant 1989 dollars)

	<u>Annual Revenues</u> (Bill. \$'s)	<u>Carbon Reductions</u> (Mill. tons)	<u>GNP Change</u> (Percent)	<u>Comments</u>
Gasoline Tax (<u>Phased-in</u>)				
\$0.33/Gal. (\$120/ton carbon)	35	18	-0.3	DRI interim results
\$1.24/Gal (\$452/ton carbon)	103	86	-2.0	DRI interim results
Oil Import Fee (<u>Phased-in</u>)				
\$6.00/Barrel (\$50/ton carbon)	23	33	-0.6	DRI interim results

ENERGY TAXES

<u>Carbon Tax per ton</u>	<u>Annual Revenues 2000 (Bill. \$)</u>	<u>Carbon Reductions (Mill. tons)</u>	<u>GNP Change (Percent)</u>	<u>Comments</u>
<u>Manne-Richels</u>				
\$5.00	7	10	not available	Provided to EPA by authors
\$10.00	14	20	not available	
\$15.00	20	30	not available	
<u>DRI</u>				
\$5.00 (1 cent/gal.)	8	27	not available	GNP losses likely to be larger than Manne-
\$10.00 (3 cent/gal.)	11	54	not available	Richels or
\$15.00 (4 cent/gal.)	23	82	not available	Jorgenson
\$25.00 (6 cent/gal.)	38	136	not available	Interpo- lated by EPA
<u>Jorgenson</u>				
\$5.00	10	68	0.1	Interpo- lated by EPA
\$10.00	14	136	0.1	
\$15.00	30	200	0.2	
\$25.00	50	272	0.2	

1/21/2020 2020-2030

POTENTIAL NONTAX INITIATIVES -- 2000

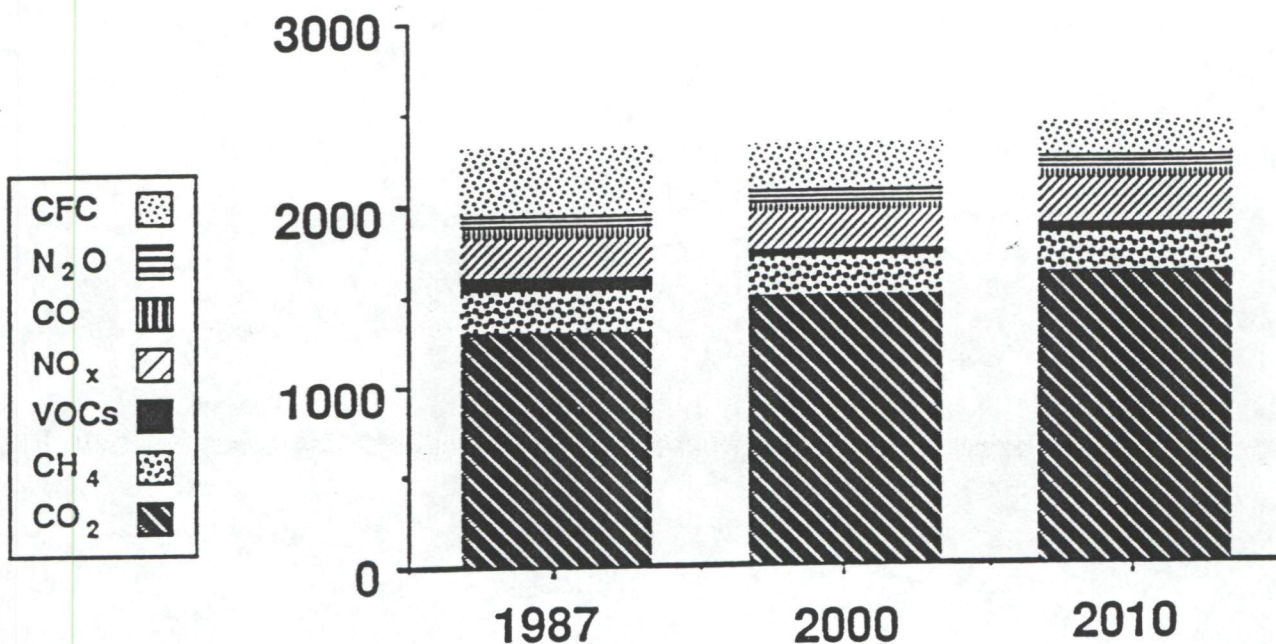
	CARBON TONNES REDUCED	ANNUAL COSTS (millions)	COMMENTS
TIGHTER LANDFILL REGULATION	39	\$431	Tighten beyond pending EPA regulations
MORE TREES	9	\$850	Double <i>America the Beautiful</i> commitment
<u>Energy Sector Options</u>			
• UTILITY-BASED INCENTIVE PROGRAMS	?	?	Provide incentives for use of cost-effective energy- saving technologies in residential sector; beyond currently proposed DOE standards.
• COMMERCIAL LIGHTING & FAN MOTOR STANDARDS	?	?	Technologies not currently covered by DOE standards.
• BIOMASS ELECTRICITY PROJECT	?	?	Short-rotation biomass and ISTIG demonstration programs.

DRAFT

Emissions

(With Current Commitments)
(100 Year GWP Factors)

Carbon Equivalents – Millions of Tonnes



	1987	2000	2010
CO ₂	1310	1502	1624
CH ₄	234	208	212
VOCs	72	48	50
NO _x	218	199	235
CO	52	45	46
N ₂ O	74	74	74
CFC	367	256	188
Total	2328	2331	2430

Clean Air

Next turn over.

Global Change file.

Presidential Styles and Substance:
Environmental Policy from Reagan to Bush

Michael E. Kraft
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University of Wisconsin-Green Bay
Green Bay, WI 54311

Norman J. Vig
Department of Political Science
Carleton College
Northfield, MN 55057

Prepared for delivery at the 1990 Annual Meeting of the American Political Science Association, The San Francisco Hilton, August 30-September 2, 1990.
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leases (CEQ 1990b). It also has high expectations for its forthcoming National Energy Strategy (NES). The NES, which is being coordinated by DOE, is scheduled for a late 1990 release, and will receive high-level White House review by OSTP's Bromley (who chairs the U.S. working group on global change) and by OMB. Bromley indicated in July 1990 that the NES will emphasize energy conservation and be sensitive to other environmental issues (Bromley 1990). Given concerns over oil imports and recent calls once again for a national energy policy, the NES is certain to become far more visible by 1991.

Two Cases of Strategic Environmental Policy: Clean Air and Global Climate Change

Finally, we turn to two major policy initiatives for evidence of how the Bush White House deals with strategic environmental issues. Both cases indicate how the president's decisionmaking style affects substantive policy choices.

✓ Revising the Clean Air Act

Proposal of major revisions to the Clean Air Act was Bush's most important domestic policy initiative in his first 20 months, and if the act is approved by Congress in 1990, it will be his administration's greatest legislative success. In contrast to Ronald Reagan's indifference to the act's renewal, Bush promised action on acid rain and smog, and broke a decade-long congressional gridlock over the nation's premier environmental policy.

Unlike global climate change, clean air has been on the nation's political agenda for over two decades, and has become a well-defined issue as a result of extensive scientific research and years of policy experience. Yet the Clean Air Act is also very costly, has major redistributive effects, and generates fierce lobbying by affected interests. These conditions made substantial White House involvement likely, and Bush's operational style

significantly affected the way the issues were defined and acted upon, both in the White House and in Congress.

The clean air proposal became a high priority for Bush immediately after his inauguration, when a special team of top White House aides was assembled to work on option papers, meet with key legislators and representatives from the environmental community and industry, and coordinate policy formulation. The major players early in 1989 included the expected EPA contingent (Reilly and William Rosenberg, Bush's nominee for EPA assistant administrator for air and radiation), but also DOE Secretary Watkins, domestic policy adviser Roger Porter, OMB's Robert Grady, presidential counsel C. Boyden Gray, and CEA economist Robert Hahn. John Sununu, who as governor of New Hampshire had favored federal acid rain control, took an active interest in the subject as the policy evolved, and supported strong control measures (Kriz 1989).

Reliance on this team of advisers shifted clean air policymaking from those with environmental expertise to a broader group less supportive of strong clean air goals and worried more about the economic implications of new federal regulations. Yet they were unable to resolve all important conflicts within the administration. When Reilly presented his full clean air plan at cabinet meetings between April and early June, debate was intense and bitter. OMB director Darman was especially critical of the high costs that would be imposed as well as EPA's use of conventional "command and control" regulation. Bush reportedly said little at the final meeting, and flew to Camp David to make his decision. To Reilly's surprise, the president backed the EPA plan, with the concurrence of John Sununu (Gabriel 1989). In this round, the president chose the most stringent options on most of the key issues, and he announced his goals to the nation at a news conference on June 12, to which he

invited representatives of the major environmental groups (Hager 1989b). This decision seems to have reflected Bush's personal commitment to the environment as well as his appraisal of the political advantages of supporting a strong clean air bill. Good personal relations between Reilly and Bush may have helped as well.

However, this was not the last word on the bill. After Bush went public with his 12-page summary and won strong backing from environmental groups and key members of Congress, John Sununu headed up a "tribunal" that met in his office over the next 39 days to work out the details of the measure to be sent to Congress. The group included Reilly, Darman, and Watkins, and was joined by others depending on the issues being discussed. Darman and Watkins often opposed Reilly's positions, particularly on acid rain, as harmful to economic growth, as did Roger Porter and economic advisers (Weisskopf 1989).

As a result of these deliberations, the president was persuaded to pull back from his initial position. He endorsed several changes in the final bill that were widely viewed as weakening the stance he took in June. When it was sent to Congress on July 21, Bush's bill was criticized by environmentalists for not living up to his earlier goals. It also was attacked by industry for going too far (Hager 1989c).

Bush's proposal had three major aims: (1) to control acid rain by reducing sulfur dioxide from coal-burning power plants by 10 million tons per year (nearly half) by 2000, and cutting nitrogen oxide emissions by 2 million tons; (2) to reduce urban air pollution (especially ozone) enough to meet clean air standards in most cities by 1995 and in all within 20 years, by using cleaner fuels and setting higher tailpipe emissions standards; and (3) to reduce emissions of about 190 airborne toxic chemicals by 75-90 percent by

2000. Bush agreed also to use an option economists have long advocated, "emissions trading," on acid rain control. The bill's cost was estimated by the administration at \$14-18 billion per year above present expenditures. However, costs and benefits of clean air measures are notoriously difficult to calculate, and estimates vary widely (Starobin 1990). In any event, the cost would be borne by industry and consumers, making the program more acceptable to a cost-conscious White House if not to industry.

Despite the president's support, congressional debate on clean air remained contentious as members sought to address issues omitted by the White House and to strengthen the president's bill. Major concerns included cost-sharing for acid rain controls (to relieve the burden on midwestern utilities), the economic costs and benefits of stringent motor vehicle emissions control standards, health standards for toxic chemical emissions, and proposals to increase auto fuel economy to reduce CO₂ levels. President Bush was largely uninvolved in the congressional process, aside from using news conferences to scold Congress for taking too long to act and raising concerns (including veto threats) about the mounting cost of congressional-added provisions.⁶

Bush's contribution to ending congressional gridlock was nonetheless important. For example, his endorsement of clean air revisions helped long-time adversaries on the House Energy and Commerce Committee, Henry Waxman and John Dingell, reach agreement on crucial auto emission limits in October 1989.

⁶ The effect of Bush's style was evident when the House Subcommittee on Health and the Environment weakened the president's much touted alternative-fuels provision. Eight of nine Republicans on the committee voted against the president's own bill. The committee's vote could be traced to the absence of any clear signal from the White House. Reilly and Sununu had sent contradictory messages to committee members (Hager 1989d).

Dingell offered a succinct appraisal of the president's effect on the process: "The President led," he said. "The public wanted it. And the House responded" (Berke 1990). The House committee took until April 1990 to enact a bill, but did so with broad agreement of committee members, leaving few choices for the House itself. The House approved its 507-page bill in late May. The Senate Environmental Protection Subcommittee, chaired by Max Baucus, moved swiftly on its own bill, approving a stronger measure than offered by the president, and the full Environment and Public Works Committee completed its mark-up of the bill in one day.

Senate consideration of the Clean Air Act became more complicated as the White House and industry opposed the Senate bill's tough provisions and high costs, and environmentalists, perhaps taking Senate approval for granted, failed to mobilize support (Shields 1990). To save the bill, Majority Leader George Mitchell began month-long, "closed door" meetings involving small groups of senators, Senate aides, White House officials (led by Roger Porter), and EPA staff. Baucus and Mitchell defended these negotiating sessions as the only way the Senate could hope to pass a highly complex and controversial clean air bill (Weisskopf 1990c). But this procedure also had two important consequences for the policy process. One was that top White House aides replaced EPA's Reilly and his staff as the most influential actors. The other was that the economics of clean air pushed aside health and environmental concerns (Hager 1990a).⁷ Environmentalists complained about the secret

⁷ Reilly attended early meetings. However, several accounts indicate that White House aides (led by Porter and Grady) took their cues not from the EPA, but rather from John Sununu. One reporter noted that administration officials "showed little deference to the man next to them" [Reilly], but would leave the room to call Sununu on the issues under discussion (Weisskopf 1990b). Apparently concern over the costs of the stronger clean air measures led to White House dominance in the process, and to the final compromises that

sessions, said the compromises weakened the Senate bill, and cited the action as yet another example of Bush's failure to be the "environmental president." In response, Reilly advised environmentalists to pay greater attention to economic impacts and to cost-effective means to achieve clean air goals (Environment Reporter 1990c).

As a result of these meetings, Mitchell was able to defeat a series of floor amendments that threatened the bill's survival, including several supported by environmentalists as well as a crucial one offered by Senator Robert Byrd of West Virginia to aid coal miners who lose their jobs as air regulations are tightened (Hager 1990b). The Senate then moved quickly, approving its massive 698-page bill on April 3 on a vote of 89 to 11. The House Energy and Commerce Committee finished its version of the Clean Air Act two days later (Hager 1990c), and the House enacted the bill on May 23, following one day of debate, by an overwhelming vote of 401 to 21.

The final outcome will depend on the work of the conference committee, which was still meeting--and making little progress--in August 1990. In yet another sign of the extraordinary attention given to the act by the White House, Congress agreed to allow Roger Porter and a "large contingent" of administration aides to participate actively at the opening session of the conference committee. Consensus exists within Congress on most of the acid rain and toxic air pollution provisions, but disagreement continues on alternative fuels, the second round of tailpipe emissions, other sections

brought the Senate bill within the limited range Bush was prepared to support. The president had threatened a veto if the costs were more than 10 percent higher than those of his original bill--or if a jobs protection provision was included. One Senate staffer suggested another reason: White House pride of authorship of the bill, and thus resistance to major changes of any kind (Shields 1990).

dealing with motor vehicles, the job-loss protection issue, and overall costs (Shields 1990). In a late July reply to a request from John Dingell, the president's chief economic adviser, Michael Boskin, warned that both the House and Senate versions of the bill remained too costly.

Revision of the Clean Air Act seems to confirm Walcott and Hult's (1987) hypothesis that where presidential goals are relatively clear but technical certainty about how to achieve them is low, decisionmaking will take place in collegial settings such as task forces. Given the uncertainty, even well-established policies like the Clean Air Act require careful assessment of a multitude of complex issues as well as political judgments by the White House. In this case, Bush relied heavily on White House aides and task forces to balance economic and environmental goals, but economic advisers dominated the process. The risk in such decisionmaking is that the president may be presented with assessments of the problem and policy options that give insufficient weight to advice from administration officials with environmental expertise and orientations. The president deserves much credit for his willingness to back renewal of the Clean Air Act. However, strategic environmental policies require a broader advisory process than evident here.

Responses to Global Climate Change

Policy for redressing the "greenhouse effect" or potentials for global climate change has aroused the greatest controversy and criticism of the Bush presidency. This is partly because of the scope and complexity of the problem, and partly because of Bush's campaign rhetoric. During the election campaign he made one of his more memorable statements on this subject: "Those who think we're powerless to do anything about the 'greenhouse effect' are forgetting about the 'White House effect.' . . . In my first year in office, I

THE WHITE HOUSE ***BULLETIN***

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DAB
MEMORANDUM FOR DR. ALLAN BROMLEY
OSTP
THE WHITE HOUSE

SUBJECT: TODAY'S BRIEFING

DATE: FRIDAY, SEPTEMBER 14, 1990 - 11:00 AM

The White House Bulletin invites you to review these debut editions of Washington's only daily briefing on policy, politics and personnel developments within the Bush Administration. For subscription information call (703) 684-2020.

MORNING'S NEWS:

Iraqi troops entered the French ambassador's residence in Kuwait City today, capturing the French military attache and three French citizens, the French foreign ministry says this morning. There are also reports that the Iraqis have forced their way into the Canadian diplomatic residence.... London announced this morning that it will send six thousand more ground troops to the Persian Gulf.... The Los Angeles Times reports this morning that Saudi Arabia and its Arab allies are urging President Bush to attack Iraqi occupying forces by mid-October. The Times also says that Iraq successfully tested a medium-range ballistic missile armed with a chemical warhead last year.... Reports from Damascus this morning say that Syria will commit as many as 15,000 additional troops to the military buildup against Iraq. Secretary Baker met with Syrian officials in Damascus today.

IN THE WHITE HOUSE AND AROUND THE ADMINISTRATION:

o As expected by Wall Street, inflation at the wholesale level rose 1.3 percent in August, the biggest gain in seven months, the government reported this morning. Higher energy costs are blamed for the rising prices. Meanwhile, retail sales dropped .6 percent last month. Lawrence Hunter, deputy chief economist with the U.S. Chamber of Commerce, stated this morning: "The decline in August retail sales is actually worse than it appears. Gasoline service station sales were reported up by \$650 million, but this was due to price increases. Retail sales figures typically overestimate actual sales because they include inflation. On an inflation-adjusted basis, sales are down by a little more than two percent from a year ago and appear to be headed even lower. This is further proof of the precarious state of the economy. What else is needed to get the budget summitters to adopt a pro-growth budget and reject misguided calls for higher taxes?"

o The President's domestic policy advisor, Roger Porter, has been asked to chair an environmental policy review board within the White House Domestic Policy Council. The high-

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level board will be announced after working out a relationship with the National Security Council on jurisdiction over international environmental issues. OMB Associate Director Bob Grady will act as staff director, and Secretaries from such key agencies as Energy, Interior, Commerce, and EPA have been asked to appoint representatives of assistant-secretary level or higher. The new board is patterned after the White House's successful Trade Policy Review Group (TPRG). "This is a way to bring everything [environmental issues] together in the White House and coordinate it in a more orderly fashion," concluded one official."

- o **HHS Secretary Sullivan plans to start a conversation this fall with the American people on the cost, accessibility and quality of the nation's health care system.** To provide more depth to the issue, Sullivan will travel to universities for a series of lectures. Meanwhile, behind the scenes, Undersecretary Constance Horner is leading a task force charged with providing Sullivan with an options paper on the issue, while she also chairs a health policy working group within the White House Domestic Policy Council (DPC). According to Horner's counselor, Arnold Tompkins, "the HHS task force is working on something to give to the Secretary this fall." The task force's findings will not be announced publicly; rather, the work will help Sullivan with his decision-making process. Sullivan then plans to make his own recommendations to the DPC, which may take a number of options to the President. Much of the health policy work currently being done in HHS for Secretary Sullivan is also being shared with the DPC working group. The process undertaken by the DPC has the Treasury Department providing cost analysis while the Census Bureau and other federal agencies offer demographic analysis and other data. Tompkins concluded that "we have nearly completed the background material. We have done a tremendous amount on assessing the problem, and now we have to figure out how to fix it."
- o **Administration officials were very pleased with the opening statements of Senator DeConcini, and to a lesser degree, Senator Heflin during yesterday's Souter nomination hearings.** One official commented, "DeConcini all but voted for Souter." Another official told the Bulletin this morning: "If you compare the statements by DeConcini and Heflin with those made by the two during the Bork hearings, it becomes clear this nomination is looking good. Some of the media commentators are talking about how well Souter's handlers have done in preparing Souter. I think it should be pointed out that what you are seeing is the essential David Souter. This is not a highly coached man. We should not be patting ourselves on the back for having prepared him well."
- o **Republican budget negotiators fear the Democrats' acquiescence on Medicare cuts may be a ploy,** according to Hill sources. The worry is that a reduction in the Medicare budget would be rejected by subsequent floor votes, and laid on the Republicans' doorstep.
- o **Meanwhile, a final obstacle in reaching a budget accord appears to lie in how to pay for the S&L crisis,** according to sources familiar with the negotiations.
- o **Labor Secretary Elizabeth Dole will address the Detroit Economic Club today,** where she will deliver a major speech on the future of the American labor force. Citing a paltry one percent annual

growth in the U.S. labor force, and the increased educational demands of the modern workforce, Dole will recommend that national competency guidelines be established for the American workforce and that the Job Training Partnerships Act be amended to focus on disadvantaged youth. Dole will speak to the International Union of Electrical Workers tomorrow in Detroit.

- o **The gargantuan efforts undertaken by departmental budget and administrative staff in preparation for a Gramm-Rudman sequestration have yielded little in the way of savings or wisdom, according to departmental budget heads.** Assistant Secretary of HHS for Management and Budget Kevin Moley told the Bulletin that, while he wished it had been otherwise, his department's preparation for the sequester has not been "a particularly useful exercise." Moley explained that "the cuts would be so large that it would be difficult to tease out priorities" from among the various programs. Moley emphasized that the threat of employee furloughs has been "terribly demoralizing" within the civil service, partly because they would fall unequally and arbitrarily on employees of different programs. Steve Dewhurst, chief budget officer at the Department of Agriculture, agreed, explaining that after reading the 29 plans developed within the Agriculture Department for OMB, he found nothing particularly useful. "Beyond a certain point, there's very little you can do," according to Dewhurst, a 25-year veteran of budget management. "This is another panic exercise," Dewhurst concluded. "You just do it." Another official told the Bulletin: "We are spending a lot of time on sequester plans, at least 50 percent. If this is a political exercise, it has been a colossal waste of valuable time. We are here to serve the public, not to act as pawns in games with Congress."
- o **Actress Linda Evans will join Secretary Lujan** on the Mall next Tuesday for the annual Take Pride in America event. Evans acts as the National spokeswoman for the Interior initiative.
- o **The White House's Office of Policy Planning (OPP) again won the NIKE Challenge's best team name contest.** Last year the office, led by Jim ("Pink") Pinkerton, took top honors with the moniker "Kinder and Gentler Soles." Yesterday, Pinkerton and his staff pocketed prize watches after edging out one hundred and thirty other Congressional, media, supreme court, and executive branch teams with the name "Read My Splits." Below the team name, OPP's shirts read "The White House Pink Tank." Pinkerton modestly gives credit to OPP staffer Will Eagle for last year's name and staffer Claudia Cummins who came up with this year's winner.

COUNTERPUNCH:

For same-day publication, call in your Counterpunches by 9:30 a.m., 684-2020

- o An **anti-hunting editorial** in yesterday's Washington Post was rejected by a number of **Interior Department officials**. One told the Bulletin that the piece was "pathetic reasoning from journalists who think a buck hunt is a sensational news story." The Post makes the point that "talking politely to hunters and rustling leaves" in an attempt to chase away game is speech protected by the Constitution, and therefore, is a right greater than that of hunting. An Administration official concluded, "I suppose that means that it is okay by the Post for me to follow a person into a movie theater and talk to them throughout a movie, or follow a person into a church and whisper in his ear throughout a sermon."

INSIDE LOOKING OUT:

The second of a two-part interview with **Terry Davies**, Assistant Administrator for Policy, Planning and Evaluation at the EPA

Terry Davies came to the Bush Administration from the Conservation Foundation, where he served as vice president while William Reilly was president there. His extensive government experience includes serving as a member of the Nixon Administration's Ash Commission, which helped draw up the blueprint for the EPA.

BULLETIN: Some commentators say the "Big Green" initiative in California will sweep the nation. Do you agree, and do think those in the federal government will have to watch it closely?

DAVIES: Yes, I think there is a fair amount of truth in that. The word I get is that the power of the initiative, in terms of winning votes, is pretty irresistible at this point. It's almost taken as a given that it is going to win. It would not surprise me if other states will try to imitate the California law, which is a peculiar kind of initiative. It is a set of disparate initiatives loosely stitched together. At least Proposition 65, which was fairly broad, was focused on a particular kind of problem. Big Green is not even that. Big Green was created by a loose coalition of organizations, each of whom brought their own particular concerns with them. They managed to put them together into one initiative. Some parts make sense. I don't understand how other parts are going to work. I think they may be counterproductive. The most controversial part is the pesticides proposals. Those trouble me as being kind of a broad sweep: 'anything that risks cancer you better ban totally.' I think it tends not to be good public policy. It does trouble me.

BULLETIN: Which parts of Big Green might pop up the soonest on Capitol Hill?

DAVIES: The pesticides. There is a strong federal role to begin with and it will cause the most political concern. It is the easiest area for the federal government to intervene in.

BULLETIN: Do you see the federal government preempting the states in these areas -- that is, saying the states are not allowed to set rules?

DAVIES: Oh, sure. There are going to be people who will urge us to do that. How it comes out, I have no idea. There have already been ongoing negotiations regarding FIFRA, the pesticide act, and the food safety questions in general. These negotiations have pretty much been independent of what is happening in California, but if the two intersect, people will become very aware of it.

BULLETIN: What new environmental initiatives are you now working on?

DAVIES: Pollution prevention is an area where there will be a bunch of initiatives. Both legislative initiatives and things to make federal agencies deal with pollution prevention and recycling. The other area for initiatives is in the international area. In respect to climate change, for example, the President has offered to host the initial session to negotiate a framework convention. This is expected to take place in February

BULLETIN: Did you put together the environmental tax incentive report?

DAVIES: You mean the Economic Incentive Report? Yes. It has been informally reviewed in a number of places. I guess I don't mind revealing the fact that such a report exists. We are going to have some sort of unveiling of it in the next few weeks so I really don't want to scoop myself. It was a task force that drew on a number of people throughout the agency. There were about a dozen people who worked on it; about half of them were from my office and half of them were from other parts of the agency. We expect it to be released by the end of the year.

BULLETIN: Will it have suggestions for new taxes?

DAVIES: It runs down a variety of possible economic incentives and it doesn't recommend any of them. It is not a list of recommendations but is rather a list of possibilities. It is very clear and emphatic that we do not have enough information in almost all of the cases to weigh the cost and benefits of going ahead with any of them. It is sort of a marketing list of ideas to pursue further.

LAST LAUGH:

- o **Johnny Carson:** The Iraqi Ambassador was offered the video tape of George Bush's speech to the Iraqi people and he refused to take it. He said he wanted "Pretty Woman" instead. (NBC The Tonight Show, 9/13/90)
- o **Johnny Carson:** But Bush is getting tough with Iraq. He said when they do take the tape, they had better rewind it or there is a \$2.00 fine. (NBC The Tonight Show, 9/13/90)
- o **Johnny Carson:** (On Bush's televised speech) During the speech to a joint session of Congress, he read a letter from a young soldier, and he quoted: "I am proud to be stationed here defending America." Now Bush didn't admit last night that (the letter) was post marked from Muncie, Indiana, 1969, and was signed Dan Quayle. (NBC The Tonight Show, 9/12/90)
- o **Johnny Carson:** Speaker Foley is not apparently used to being on national television. He looked like somebody you'd see on a 7-Eleven security camera who just stuck a bag of Fritos under his jacket. (NBC The Tonight Show, 9/12/90)
- o **Johnny Carson:** Sec. James Baker has been going around the world trying to get countries to chip in, and Democrats have criticized, as you probably know, Japan and Germany for not giving us economic help in the Gulf crisis. Japan and Germany said, 'hey,' that's not how it works...we start the war, then you pay us. (NBC The Tonight Show, 9/12/90)

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- END OF FAX -

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AMBASSADOR'S OFFICE

1/26

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UNCLASSIFIED FAX

FROM: WSHDC AMB-

DATE: NOV. 2/90

TO: DR. ALLAN BROMLEY
ASSISTANT TO THE PRESIDENT
FOR SCIENCE AND TECHNOLOGY
FAX NBR: 395-3261

Currently
Hydrogen storage costs \$1-3/mm Btu
" production " \$6-10/mm Btu
Electrolytic hydrogen " " \$15-25/mm Btu

This production cost corresponds, I'm told, to gasoline at \$4/gallon at the refinery. Thus, the statement that hydrogen is viable as a niche fuel - having breakthrough developments. Cool papers

SUBJECT: HYDROGEN MATERIAL

AMBASSADOR BURNEY ASKED ME TO TRANSMIT TO YOU THE ATTACHED PAPERS ON HYDROGEN THAT WERE PREPARED BY MR. STUART OF ELECTROLYSER.

*Karl Erb
Does anyone think make any sense?
Stuart is a solid guy - thought his 2 papers.*

Neil Reeder

NEIL REEDER
EXECUTIVE ASSISTANT
TO THE AMBASSADOR

Yes - DOE & NASA conduct R&D re. hydrogen as a fuel - the NASP would be H-powered - and DOE does a fair amount of R&D on electrolytic production of hydrogen. Also, the president has just signed a bill authorizing a program with full funding for the short-term. Hydrogen R&D will be a niche fuel, at best. I don't think it's a good idea to have a full program with full funding for the short-term. Hydrogen R&D will be a niche fuel, at best. I don't think it's a good idea to have a full program with full funding for the short-term.

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"GLOBAL WARMING AND THE POTENTIAL ROLE FOR HYDROGEN"

PRESENTATION BY ALEXANDER K. STUART

TO

STANDING COMMITTEE ON ENVIRONMENT
HOUSE OF COMMONS
OTTAWA, CANADA
APRIL 3RD, 1990.



Electrolyser

STANDING COMMITTEE ON ENVIRONMENT, HOUSE OF COMMONS, OTTAWA
"GLOBAL WARMING AND THE POTENTIAL ROLE OF HYDROGEN"
ALEXANDER K. STUART, APRIL 3RD, 1990.

Introduction

I am most honoured by the invitation to present to you today ideas about hydrogen as clean energy - a subject to which I have devoted most of my business life, following my father's earlier work.

In 1867, Jules Verne, in his novel "The Mysterious Island", described hydrogen and oxygen from water as the inexhaustible "coal of the future". Whether Jules Verne provided the inspiration I do not know, but hydrogen energy has had very early roots in Canada. About 1905, A.T. Stuart of Toronto collaborated with Prof. Lash Miller at the University of Toronto to develop electrolytic hydrogen (that is, hydrogen made from water by the process of electrolysis) as the appropriate link between Ontario surplus hydroelectric power and our Ontario need for fuel (almost all of which was - and is - imported). A whole matrix of technologies were developed based on hydroelectric energy and hydrogen and oxygen, linked with carbon in the form of coal, peat, lignite and biomass such as wood waste. Early sponsorship was obtained from the old Toronto Power Company, and in 1924 the Water Power Branch of the then Department of Mines and Resources in Ottawa took over responsibility.

A network of industrial application technologies was conceived and some were developed. Hydrogen and oxygen produced electrolytically from water were used to produce "town gas", synthesis gas for the production of synthetic chemicals and reducing gas for the direct reduction of iron ore to iron without melting; hydrogen from electricity was proposed as a transportation fuel, and tested as a heating fuel. The development program was assumed by Ontario Hydro in the depths of the depression but, after two years of successful demonstration, the program was terminated.

Electrolytic Hydrogen Production

What has endured, however, is a strong base of Canadian technology in water electrolysis, and this led to the founding in 1948 of our company, The Electrolyser Corporation Ltd. Electrolyser has since supplied some 700 hydrogen plants to users in 90 countries, and we have become one of the two or three most active firms worldwide in this special area.

I say "special area", because electrolysis today produces less than 1% of the world's industrial hydrogen. About 76% of Canada's hydrogen is made from natural gas, to produce synthetic ammonia and to upgrade heavy oils; about 23% is produced from oil and is used internally in the refining process.

Nevertheless, electrolytic hydrogen has an industrial niche and is used throughout the world (particularly in developing countries) in the food industry for the processing of fats and oils, in thermal electric power stations where hydrogen is used to cool the generators, in the production of flat glass by the Pilkington "float" process, in the reduction of metal powders and ores, in the electronics industry for the manufacture and processing of semi-conductor materials, in the production of a large variety of chemicals such as hydrogen peroxide and nylon, in the processing of television tubes and electric lightbulbs, of electrical steels and stainless steels etc. A very few large electrolytic plants produce hydrogen for synthetic ammonia, the basis of all nitrogen fertilizers.

At the low end of the capacity scale, small electrolytic hydrogen generators were developed in cooperation with Environment Canada and are now used throughout the world to inflate radiosonde weather balloons, which are a principal tool of weather forecasting.

The Energy Role of Hydrogen

In 1970, when the first of the OPEC crises was brewing, an American report proposed (in Canada, we like to say re-proposed!) that hydrogen, derived from water using non-fossil primary energy sources such as hydroelectric, solar,

The Energy Role of Hydrogen (Continued)

nuclear, geothermal and tidal, could provide a clean substitute for hydrocarbon fuels; and that these non-fossil primary sources would be sustainable and well distributed. At about the same time, the first papers for the popular discussion of global warming began to appear. In the hydrogen energy field, we have watched the concept move from academic hypothesis by a few to general acceptance by the majority of world atmosphere scientists - with continuing debate on the timing, the intensity and the effects.

When hydrogen is burnt with air in an internal combustion engine, the product is water vapour, a natural constituent of the environment, with a slight contamination of nitrogen oxide. By taking advantage of the wide combustion limits of hydrogen, the output of NO_x can be minimized; and when the hydrogen is produced from water by electrolysis, there is co-produced the exact amount of oxygen necessary for the subsequent combustion of the hydrogen. This fact itself can be of environmental significance, as we continue to attack the forests and other oxygen generators of the world.

Going an important step further, if instead of the internal combustion engine, the hydrogen is delivered to a fuel cell on board a vehicle and converted electrochemically in the fuel cell back to electricity to drive the wheels, not only is energy efficiency increased by a factor of up to two or three, the formation of the NO_x impurity is eliminated.

Hydrogen - and I would add oxygen - constitute, environmentally, the ultimate carbon-free fuel combination for energizing a cleaner and more environmentally stable world.

In the early 1970s, when hydrogen energy technology got its recent start, the driving force was oil and gas depletion, and strategic exposure to the turbulent Middle East. While I (with many) believe that these factors will return, the strongest rationale today is the immense contribution that hydrogen can make to a healthier atmosphere, through the supplementation and eventual substitution of fossil fuels.

Electrolysis Development in Canada

In the mid 1970s, responding to both the depletion and the environmental arguments, Electrolyser joined with Noranda Inc. and later Hydro Quebec in developing the world's largest electrolyzers, of much higher electrical efficiency and lower capital cost. The interest was to move electrolysis from small-scale to plant modules sufficiently large to make a significant energy contribution. In 1982, the first full-size unit cell prototypes were put into operation at IREQ, the research establishment of Hydro Quebec at Varennes. In 1987, the first industrial plant was commissioned at Becancour, Quebec in a capacity of 7 MW. The owning company, HydrogenAL Inc., is a partnership of Hydro-Quebec and Canadian Liquid Air and the hydrogen is liquified for supply to Canadian industries and for export to the United States. In 1987, a second and larger installation (expandable to 15 MW) was commissioned at Curitiba in Brazil. The hydrogen is used for the production of hydrogen peroxide as an environmentally benign bleaching chemical for the pulp and paper and textile industries. Both installations are highly successful.

(SLIDES)

The large EI-250 Electrolyzers, operating at 100,000 amperes DC, are the result of an effective partnership between industry and government. Fifty percent of the development cost was provided by the industrial partners and 50% by the government of Canada through the Program for the Advancement of Industrial Technology (PAIT) and, on its termination, by the then Energy Division of the National Research Council. In November 1984, NRC's Energy Division was terminated. Fortunately, Energy Mines & Resources undertook to continue the Canadian Hydrogen Program, although at a very much reduced level of funding.

International Hydrogen Energy Initiatives

With its early insights in hydrogen energy, Canada has played an active role internationally in hydrogen energy development. In 1978, Canada was a founding signator of the International Energy Agency Implementing Agreement on hydrogen production. Canada has since continued its active participation. Expenditure on the federal hydrogen program, which had reached \$7 million per year by November 1984, was subsequently reduced to a level of approximately \$1 million per year. Provincial expenditures, especially in Quebec, added to the Canadian total, but significant increases will now be necessary to sustain any effective momentum in the future and to facilitate international exchange.

I have described earlier some of the important industrial applications for hydrogen gas. Today, except for the burning of waste hydrogen to recover heat, the only application of hydrogen as fuel is in rocket propulsion. Hydrogen was of course the fuel for the Apollo missions to the moon, and will be the fuel for the U.S. National Aerospace Plane. As an aircraft fuel, the advantages of hydrogen are quite unique. For the same energy content, hydrogen weighs only 40% as much as conventional jet fuel. In addition, the cooling of wing surfaces by liquid hydrogen is stated to improve fuel efficiency by as much as 25%. Recognizing these advantages, a Soviet Tupelov 155 subsonic aircraft (rather similar to a Boeing 727) recently made an historic flight with hydrogen as fuel and hydrogen aircraft work is reported now to be underway in Germany, Britain and the U.S.A.

Terrestrially, there have been many successful hydrogen vehicle demonstrations including private automobiles, small trucks and buses and even an agricultural tractor. In Toronto in 1984, at the World Hydrogen Energy Conference, eight vehicles provided an operating demonstration at the University of Toronto. However there have remained very strong technology barriers to any broad use of hydrogen as a transportation fuel, or as an energy carrier in general. These barriers constitute at the same time a challenge and a very significant opportunity for Canadian research and development, for Canadian industry and, eventually, for the improvement of the global atmosphere. Hydrogen energy could begin to be used today, in special favourable situations, if we could close the critical technology gaps which are restricting its application. These gaps are in the areas, not so much of production, as of storage and handling, and reconversion to electricity and shaft power.

The Technology Gaps

New breakthroughs are required in the area of hydrogen storage, handling and distribution. Hydrogen has to be convenient before it will be used. There are at least five categories of hydrogen storage where improved technology is needed to make hydrogen energy practical:

1. On-board storage for vehicles - to be light weight, compact, quickly rechargeable, safe and lower in cost than present methods.
2. Fixed storage of medium capacity for industrial hydrogen plants and at remote hydrogen energy generating sites, which may be based on mini-hydro resources or photovoltaic electricity generation.
3. Larger bulk capacity for storage of hydrogen made from off-peak power to generate peak power and accomplish load levelling.
4. Bulk storage for the marine transport of hydrogen, so that hydrogen can be made in centres of low cost hydroelectricity and moved to energy intensive markets. This is particularly important for Canadian distances and resource locations.
5. Very large bulk storage for hydrogen produced from surplus seasonal energy. Here, with the slow annual use cycle, storage capital cost will be the driving factor and underground storage is probably the best option.

Hydrogen is not as convenient as a liquid fuel such as gasoline or methanol. However it has many redeeming characteristics and there have been outstanding accomplishments in metal hydride containment of hydrogen, and in liquid hydrogen technologies; in my view, however, the "Philosopher's Stone" for hydrogen will be the discovery of a truly light weight low cost "hydrogen sponge" - perhaps some organic resin which can operate at a low pressure or temperature differential in an absorption/desorption cycle and which can absorb hydrogen to some incredible density. This is the top hydrogen challenge - and we will not be ready for large scale use of clean-air hydrogen vehicles until we have better answers.

The Technology Gaps (Continued)

Also desperately needed are effective and efficient low cost reconversion technologies, i.e. hydrogen to electricity. I have referred already to the fuel cell, which might be described as a kind of storage battery which is kept continually charged by the introduction of hydrogen and oxygen to the electrode areas. Progress here is most encouraging at this time. The Canadian company Ballard Power Systems of North Vancouver is believed to be on the verge of a major success, in terms of high energy density, energy efficiency and prospectively acceptable capital cost. The Ballard design was initiated under the Canadian Hydrogen Program, with further support from the Department of National Defense. Other important reconversion options include hydrogen/air gas turbines for propulsion and peak power generation; hydrogen/oxygen turbines and steam generators, again for propulsion but particularly for peak power generation; and magneto-hydro-dynamics (MHD), which produces electricity at high efficiency employing a hydrogen/oxygen plasma.

Success in these areas of storage and electricity generation from hydrogen could open important hydrogen energy applications in transportation, in energy conservation through the generation of peaking power at electric utility plants and in energy transmission.

Electricity and hydrogen, from non-fossil sources, together offer the most promising route to the solution of global warming. By developing today in Canada the technologies which will provide such relief, we shall in time not only solve many of our own environmental problems but create exportable technologies which will return our investment many-fold.

An Expanded National Program

Canada has had the benefit of two major studies on hydrogen - the 1981 report "Energy Alternatives" by the House of Commons Special Committee on Alternative Energy and Oil Substitution; and the 1987 report of the federal Advisory Group on Hydrogen Opportunities, chaired by Dr. David Scott, entitled "Hydrogen - National Mission for Canada". Now is the time, in the context of the environmental challenge, to put in place a national plan for Canada in hydrogen energy and to put significant resources behind it. The Hydrogen Industry Council, on the request of the government, has submitted strategic reports and recommendations and active discussions are underway.

An Expanded National Program (Continued)

The national plan should be strategic in nature, should encompass all stages - fundamental research, precompetitive research, industrial applied research, and final demonstration. The plan should be both pro-active and re-active - pro-active is identifying and supporting our existing strengths in hydrogen and in identifying the technology gaps and seeking to fill them; and re-active in guiding the assessment of the specific projects put forward by the the industrial and scientific community in accordance with, among other factors, a hydrogen strategic plan. In this way, resources can be channelled effectively and significant results achieved - an integrated whole (or whole segments) which can be brought into early use, stimulating onward momentum. We should follow the Japanese example of parallel basic research and hands-on demonstration, with feedback between the two.

Several provinces have valuable hydrogen programs and provincial interest is increasing. There is an excellent opportunity for a well-coordinated federal-provincial collaboration in the hydrogen field. As stated in the Parliamentary Report "Energy Alternatives", "... a hydrogen system will evolve only if there is a strong political will to make it happen". This is as true in 1990 as it was in 1981.

An effective strategic plan is needed to mobilize our Canadian science resources in government, industry, universities and research institutions. The Japanese, the Germans and the French have been highly successful in integrating their financial scientific industrial and governmental resources to achieve important strategic objectives in science and industry. We need a Canadian equivalent and we must find out how to link that equivalent with the power of our market system.

Early Hydrogen Opportunities

I would like to describe some of the early contributions which hydrogen could make. The opportunity may come first in energy storage and load levelling, and in the extending and "cleaning" of hydrocarbon fuels technology; later, hydrogen may start to replace hydrocarbon fuels, at first only in special applications or at remote locations; and later, more universally, in bringing cleaner air to our cities.

Early Hydrogen Opportunities (Continued)

An example of hydrogen's potential for "hydrocarbon cleaning and extension" exists in the development of the oil sands and heavy oils of Western Canada. In these environmental times, the future thrust of policy will probably be to encourage processes which maximize the utilization of the carbon atom - that is, processes which produce as much fuel energy as possible per unit of CO₂ released - and which produce a maximum proportion of transportation rather than heating fuels. The major difference between oil sands bitumen (or for that matter coal) and conventional light crude oil is the ratio of hydrogen to carbon. The higher the hydrogen, the lighter the product and the more energy produced per unit of carbon combusted. At present in oil sands processing, the hydrogen-to-carbon ratio is adjusted by rejecting carbon. If coal is used as the external fuel for thermal cracking, according to the Advisory Group report almost 3 tons of carbon dioxide are released to the atmosphere for every ton of synthetic light crude oil product. Newer projects will instead adjust the hydrogen-to-carbon ratio by adding hydrogen, initially made by steam methane reforming of natural gas, thus reducing processing emissions of carbon dioxide by over 50% to about 1.2 tons of CO₂ per ton of syncrude products.

Beyond this however, there are preliminary proposals to integrate electrolytic hydrogen and oxygen with oil sands technology. Where the heating and electrolysis energy is hydroelectric or nuclear, virtually all of the carbon in the bitumen would pass through to the synthetic crude oil product. The nuclear system, for example, if operated in conjunction with the oil sands, would have as outputs electricity, hydrogen, oxygen, steam and hot water. All of these are valuable in carrying out bitumen recovery and in processing it in a more environmentally benign and energy efficient way. Electrolysis capacities involved would be in a range of 5 to 10 MW/1000 barrels of oil per day and a major oil sands operation of, say, 120,000 barrels per day would require over 600 MW of electrolysis, if all of the hydrogen were supplied electrolytically.

Alternatively, a promising electrolysis/hydrocarbon integration would utilize the byproduct electrolytic oxygen to gasify the very heavy residuals, producing a significant portion of the hydrogen requirement by partial oxidation. A relatively small release of carbon dioxide would be involved, at a level of about one-third of a ton per ton of syncrude product.

Early Hydrogen Opportunities (Continued)

At present, also in Canada, there is an interesting example project of the move to pure electrolytic hydrogen as a transportation fuel. This is the Euro-Quebec Hydro-Hydrogen Pilot Project. The European Community and the Government of Quebec are jointly funding a \$4 million study of the production of electrolytic hydrogen at Sept Iles, Quebec. Approximately 100 MW of hydroelectric power would be used to produce 20 million cubic feet of hydrogen per day; and this non-fossil derived hydrogen would be transported by sea to Hamburg, Germany, probably in liquid form. There it is proposed to fuel transit vehicles (to provide cleaner air in that city) and possibly a hydrogen-powered version of the Airbus aircraft, as well as to meet other hydrogen requirements.

The linking of solar energy to hydrogen production is being studied in several projects, including at an existing 350 kW photovoltaic site in Saudi Arabia near Riyadh. My company, Electrolyser, is commencing a project in this field in association with the Ministry of Energy of Ontario. The purpose will be to demonstrate that there can be a direct and simplified linkage between a photovoltaic array, generating electricity from sunlight, and an electrolyser, without a complex power conditioning interface. If this effort is successful, we should be able to demonstrate (in such places as California or in remote communities of Canada), the local generation of clean fuel from solar energy. As can be envisaged, there is a very important potential in third world countries for such a technology. The Germans believe that with the constant decrease in the cost of photovoltaic electricity, it will be possible to generate hydrogen in North Africa and Saudi Arabia for the supply of clean fuel to continental Europe. Similarly, for Canada, one can envisage the export of remote hydroelectricity, (a concentrated solar energy), in the form of clean hydrogen fuel, to urban centres of concentrated energy use. Here again, economically effective hydrogen transportation is the important key.

It is our conviction that these significant niches for clean hydrogen fuel will gradually grow. It will be a process of decades, commencing initially with supplementation and enhancement of hydrocarbon fuels for a cleaner environment followed eventually by gradual replacement during the next century.

Observations on Policy Aspects

In closing my remarks, I should like to make a few general observations.

1. There has been a debate between generation of "large energy" in centralized systems and generation of (the more beautiful) "small energy" in dispersed locations. In my view, to be realistic, we need both. The world is continuing to urbanize and we do not know how to reverse this trend. I am a Torontonian, born and bred, and I, with many of my fellow Torontonians, would be happy to share our growth and prosperity with the rest of Canada - in fact many of us who have to live in Toronto wish we could stop growing, at least at such a pace. But no one seems to know how to limit urban growth, either in this country or the Third World. For energy, therefore, the practical problem is how to deliver concentrated clean energy in large quantities to a concentrated population. This we must learn how to do, and I feel we can learn long before we will have learned how to "de-urbanize". I feel that electricity and hydrogen probably constitute the only long term solution.
2. Our new-found knowledge about the biosphere has produced an index of greenhouse gases - a comparative table showing the potency for global warming of the various gases we are releasing to the atmosphere. A copy of this table is attached taken from "The Hydrogen Economy and Global Climate Change" (Federal Interdepartmental Panel on Energy R&D, May 29, 1989). This table shows that CFCs have an index of up to 20,000 - that is, one cubic foot of CFC released has the global warming impact of 20,000 cubic feet of CO₂. In our planning, we must also take into account that natural gas has an index of 25. This implies, if the table is correct, that a leakage of only 4% of natural gas to the atmosphere without combustion will double the global warming impact and raise it approximately to that of coal combustion, per unit of heat obtained. Canada's natural gas leakage rate is under debate but is reported by some to be in the range of 3% to 5%. The Soviets, on the other hand, report a leakage rate to the atmosphere of some 16%. With this, the arithmetic shows that Soviet natural gas contributes to global warming at a rate more than double that of coal combustion. Natural gas has important advantages but to obtain them, uncombusted emissions have to be minimized

Observations on Policy Aspects (Continued)

3. This brings up the critical point that we must somehow, and soon, develop a practical method for bringing environmental impact into the cost equation, in determining alternative courses of action and allocations of resource. I am personally conscious that the search has gone on for over 25 years, by many, to develop such a value system. We must find it so that market forces can be mobilized to bring about environmental improvement, in the context of "true cost". I tend to agree with Mrs. Brundtland that, left to itself, the market system cannot be expected to protect the environment in a timely fashion - but, pointed by policy and cost economics in the right direction, the system can deliver very effective results.
4. Most courses of action for improving the environment add to short term cost and, particularly, are more capital intensive than present practices. Under our current interest rate regime, capital is extremely expensive. This is a discouragement to industry to innovate, to invest in cost reduction and in environmental improvement. Our competitors in Japan and Germany have access to capital at much lower cost. It is a more severe problem therefore for Canadian companies to make the necessary high risk investments in research and in environmental technology, when the visible and immediate monetary returns may be less than if the funds were invested in treasury bills. We are without question injuring our long term industrial position and our strategic science. We are also making it more difficult to take effective action to help the environment.
5. My final point concerns what may be a difficulty in getting a comprehensive assessment of the aggregate benefits to Canada of hydrogen, within our government structure (and within the government structure of most other countries - the problem I am about to describe is a common one). While primarily in the energy mandate, hydrogen brings important benefits to the mandates of environment, external trade, transportation, industrial development, the advance of science and defense. All of these are represented by separate government departments. Our provincial governments have similar problems, in delivering the right aggregate value answer, and having that answer expressed in funding levels reflecting the total benefit to Canada, rather than just the specific departmental value. We can hope that our system is equal to this holistic challenge.

Thank you indeed for this valuable opportunity to direct the Committee's attention to the environmental potential of hydrogen.

ANNEX I**The Greenhouse Effect**

The Greenhouse Effect is defined as a warming of the lower part of the Earth's atmosphere by gases which absorb infrared radiation. The "greenhouse gases" now in the atmosphere include carbon dioxide, ozone, chlorofluorocarbons (CFCs), methane and nitrous oxide (N_2O). Some of these gases occur naturally in the atmosphere, others are man-made. It is estimated that "primordial concentrations" of carbon dioxide and water vapour in the atmosphere raised the surface temperature of the earth by $33^\circ C$, from about $-18^\circ C$ to $15^\circ C$.²⁰ This natural greenhouse effect, in turn, made life on Earth as we know it today, possible. Since the beginning of the industrial revolution, the concentration of all of these gases increased, as shown in Table I, raising concern about their long term environmental consequences.

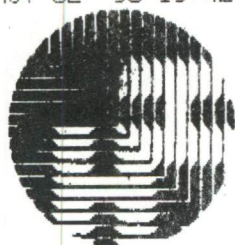
Table I. Present greenhouse gas concentrations in air, rates of increase and estimated pre-industrial levels.²⁰

Gas	Concentration in air ²		Present rate of increase per year	Efficiency as greenhouse gas
	Pre-industrial	1986		
Carbon dioxide (CO_2)	275 ppm	346 ppm	1.46 ppm (0.4%)	1
Methane (CH_4)	0.75 ppm	1.65 ppm	17 ppb (1%)	25
CFC-12 (CCl_2F_2)	zero	400 ppt	19 ppt (5%)	20,000
CFC-11 (CCl_3F)	zero	230 ppt	11 ppt (5%)	17,500
Nitrous oxide (N_2O)	280 ppb	305 ppb	0.6 ppb (0.2%)	250
Ozone, tropospheric (O_3)	15 ppb?	35 ppb	3ppb? (1%) North. Hemisp. only	

² ppm = parts per million

ppb = parts per billion

ppt = parts per trillion



Electrolyser

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Hydrogen/Oxygen Gas Plants
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Gas Compression Systems
Gas Purification Systems

**"HYDROGEN PRODUCTION - TOMORROW"
A PERSPECTIVE ON ELECTROLYSIS**

Alexander K. Stuart

NATIONAL HYDROGEN ASSOCIATION
1ST ANNUAL MEETING
"HYDROGEN: YESTERDAY, TODAY AND TOMORROW"

Washington, D.C.
March 8th, 1990.

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"HYDROGEN PRODUCTION - TOMORROW"
A PERSPECTIVE ON ELECTROLYSIS BY ALEXANDER K. STUART
MARCH 8TH, 1990.

Introduction

It gives me a lot of satisfaction to speak of electrolysis as a "tomorrow" technology - which it most certainly is and perhaps on a scale beyond my imagining. But, as someone who has practiced in the field industrially for years, if there is one single message I would like to bring, it is that electrolysis is also a "today" technology and on a large, efficient multi-megawatt scale.

I say this with some emphasis because, whatever may be the history and the present reality, it is very difficult for large energy people, those who power the world, to accept that water electrolysis is not just the small demonstration everyone remembers in high school, nor just small systems for gas chromatographs or the cooling of generators in power stations - but is available now in 100 MW module blocks, at energy efficiencies over 80% and at capital costs much reduced from earlier levels. Under the right circumstances of primary energy, electrolysis today is ready to contribute meaningfully (and cleanly!) to the energy supply systems of the world.

Energy Markets

These contributions will come first in energy storage and load levelling, and in extending and "cleaning" hydrocarbon fuels; later, hydrogen will start to replace hydrocarbon fuels, at first in special applications or at remote locations and later more universally, bringing cleaner air to our cities.

As an example of the potential for hydrogen's hydrocarbon "cleaning" role, there exist in Canada and in other countries large reserves of heavy oil and oil sands. In Western Canada, the resource is truly enormous, matching the Middle East in total energy potential. The further development of these oil sands is essential; and now, in these environmental times, the policy thrust will be toward processes which maximize the utilization of the carbon atom - that is, produce as much fuel energy as possible per unit of CO₂ released - and which also produce a maximum proportion of transportation rather than heating fuels. As many here will know better than I, the major difference between oil sands bitumen (or for that matter coal) and conventional light crude oil is the ratio of hydrogen to carbon. The higher the hydrogen, the lighter the product. At present in Western Canada, this ratio is adjusted by rejecting carbon. If coal is used as the external fuel for thermal cracking, almost 3 tons of carbon dioxide are released to the atmosphere, for every ton of synthetic light crude oil product. Newer projects will instead adjust the hydrogen/carbon ratio by adding hydrogen, initially made by steam methane reforming of natural gas, thus reducing processing emissions of carbon dioxide by over 50% to about 1.2 tons of CO₂ per ton of syncrude products.

Beyond this, however, there are preliminary proposals to integrate electrolytic hydrogen and oxygen with tar sands processing. Where the heating and electrolysis power is hydroelectric or nuclear, virtually all of the carbon in the bitumen would pass through to the synthetic crude oil product. The nuclear system would have as outputs electricity, hydrogen, oxygen, steam and hot water. All of these are valuable in carrying out bitumen recovery and in processing in a more environmentally benign and energy efficient way. Electrolysis capacities involved would be in the range of 5 to 10 MW per 1000 barrels of oil per day and a major oil sands operation (say 120,000 barrels per day) would require over 600 MW of electrolysis, if all of the hydrogen were supplied electrolytically.

In an alternative promising electrolysis/hydrocarbon integration, the by-product electrolytic oxygen can be used with steam to gasify the very heavy residuals, to produce a significant portion of the hydrogen requirement by partial oxidation. A relatively small release of carbon dioxide would be involved (about one third of a ton per ton of syncrude product).

At present, also in Canada, there is an interesting example project of the onward move to pure electrolytic hydrogen as a transportation fuel. This is called Phase II of the Euro-Quebec Hydro-Hydrogen Pilot Project. The European Community and the Government of Quebec are jointly funding a \$U.S. 3.5 million study on the production of electrolytic hydrogen at the iron ore port of Sept Iles, Quebec. Approximately 100 MW of hydroelectric power will be used to produce 20 million cubic feet of hydrogen per day; and this non-fossil-derived hydrogen will be transported by sea to Hamburg, Germany, probably in liquid form; there it is proposed to fuel both a significant portion of the bus fleet of Hamburg and a hydrogen-powered version of the Airbus aircraft, as well as to meet other hydrogen requirements.

The linking of solar energy to hydrogen production is being studied in several projects, including at an existing 350 kW photovoltaic site in Saudi Arabia near Riyadh, where Hydrogen Systems of Belgium is installing an electrolysis unit. My company, Electrolyser, is commencing a smaller project in the solar field, in association with the Ministry of Energy of Ontario. The purpose will be to demonstrate a direct and simplified linkage between a photovoltaic array and an electrolyser, without a complex power commissioning interface.

Finally, in the context of the "today" reality of electrolysis, industrial electrolysis systems in the range of few kilowatts to 20 megawatts are operating in virtually all countries of the world. The uses include hydrogenation of vegetable and marine oils for the food industry; the preparation of important industrial chemicals such as fatty amines, nylon intermediates and hydrogen peroxide; the reduction of metal oxides; sintering and heat treating atmospheres for a range of metallics such as tungsten and molybdenum carbide, stainless steel and grain - oriented electrical steels; the production of semi-conductor materials and components; TV tubes and float glass manufacture; the cooling of generators at thermal power stations; the inflation of meteorological balloons and the supply of merchant hydrogen and oxygen gases.

Off-Peak Power

Electrolysers of good design are essentially rugged and highly flexible, and have physical lives in excess of 20 years. The ability to absorb variable quantities of electric power is an increasingly valuable characteristic - electrolysers are the ideal "sponge" for electric power. For example our EI-250 - Electrolysers have been specifically designed to be modulated automatically and very rapidly from full load (or overload) down to less than 20% load. Unlike many chemical processes, in electrolysis the energy efficiency actually increases at lower loads.

The "electricity sponge" characteristic of electrolysis obviously enhances its value as an accessory to the central electric system and also in alternative energy applications, where the energy source may be intermittent, such as with solar or wind. The high energy efficiencies (80 to 85%), which are already being obtained in large electrolysis plants, will probably increase over time in liquid electrolysis to as high as 90%. However, valuable as these ultimate efficiency savings (in the order of 5%) may be, there are far greater savings to be gained by integrating the electrolyser with lower cost primary power sources; and in designing the electrolyser system to be able to use the more fluctuating and lower cost categories of electricity.

At these high levels of efficiency, electrolytic hydrogen comes close to being another form of electricity. Electric utilities may some day supply electricity and hydrogen, promoting full utilization of the power station capital investment.

Significant advances are now being made in technologies to convert hydrogen back to electricity (such as fuel cells, magnetohydrodynamics and hydrogen-oxygen steam turbines). I believe there may soon be an actual demonstration of hydrogen storage and peak power generation, for load levelling and the supply of peaking fuel.

Electrolysis - The Process

For those not familiar with the technology of electrolysis, I would like to provide a thumbnail sketch of the electrochemistry and the engineering practice.

Referring again to that high school demonstration, the rate of hydrogen production is directly proportional to the current in amperes flowing through the cells. The energy efficiency is inversely proportional to the voltage (or "electrical pressure") required to cause the desired current to flow. The cell voltage of an operating electrolyser is made up of three components. One of these, the thermodynamic reversible voltage, the cell designer can do nothing about. Below this voltage no current can possibly pass. The other components, which are more amenable, are the electrode overvoltages and the cell internal resistance. The electrolysis researcher attacks the electrode overvoltages by developing special electrocatalysts and by achieving as large a micro-surface on the electrodes as possible. The internal resistance is attacked by designing to minimize the distances the electric current must travel through the solid elements of the cell, and through the electrolyte (which is the conductive solution or material through which the current must flow between the electrodes). Where the current leaves the negative electrode (or cathode), hydrogen is formed; and where it enters the positive electrode (or anode) oxygen is formed.

In terms of energy efficiency, if a cell is so successfully catalyzed that it can operate at 1.5 volts (the "thermoneutral voltage"), in electrical terms the efficiency would be 100% - that is, the fuel value of the hydrogen produced would be equivalent to the electric energy consumed. As I will mention later, these are not impossible targets to obtain (although extra heat will be needed); nevertheless, all practical water electrolyzers today operate at some voltage in excess of 1.5 volts, in order to achieve an economic rate of production. Each cell design has a characteristic performance curve but in general a small increase in voltage produces a large increase in current (or production rate), at the expense of energy efficiency. There is therefore a

Electrolysis - The Process (Continued)

trade-off, with all electrolyzers, between energy efficiency and capital investment. For example, where operation is continuous and power is expensive, the economic production point (in amperes or current density) will be at lower and more efficient current density levels, than if power supply is intermittent and at low cost, where the objective may instead be to minimize capital investment.

Electrolysis Engineering

Electrolyser designs fall into two categories, called unipolar and bipolar. In recent years, very great advances have been made in each. Essentially, "unipolar" means that each electrode is of one polarity (positive or negative) and as a consequence produces only one gas (either hydrogen or oxygen). Many electrode elements are grouped together electrically in parallel, within an individual cell tank. Total amperes and hydrogen capacity can be very high, following the practice in chlor-alkali cells and in aluminum pot lines.

On the other hand, with "bipolar" construction each electrode is positive on one side (where oxygen is made) and negative on the other side (where hydrogen is made). The electrode elements within the unit are arranged in series in a stack, rather than in parallel, so that total voltages across the assembly are quite high (several hundred volts) and currents are low. The gases are led through ducts from each cell electrode compartment through a manifold to external gas/liquid separators.

As may be expected, there are advantages and disadvantages to both designs and both are in service today and are under further development. Very briefly, the unipolar electrolyser offers electrical and mechanical simplicity because of low voltage (under 2 volts per unit). Individual cell modules can be isolated for overhaul, thus ensuring sustained production. Due to simplicity and the absence of external auxiliary systems, unipolar electrolyzers can be safer and inherently lower in capital cost.

Electrolysis Engineering (Continued)

Bipolar electrolyzers are generally more compact and, because of short current paths, offer less internal resistance. However it is usually necessary to operate at higher and more stressful current densities, to modify a higher capital cost. Operating efficiencies of the two types are generally comparable. Due to high total voltage across the bipolar cell block, care must be taken to minimize bypass currents and corrosion because of the numerous small interconnecting electrolyte passages. For the same reason, it is more difficult in bipolar design to retain electrode activation because of potential deterioration during shutdown. Bipolar design can be more easily pressurized, where this is considered advantageous.

All commonly used water electrolyzers today are of the alkaline type, employing potassium hydroxide solution as the electrolyte. An alternative solid polymer electrolyte system was initiated by General Electric Co. as a consequence of the space program and development is continuing in Switzerland, Japan and France. Potentially this approach offers very high current density and therefore compactness, low cost and high efficiency. However the acid nature of the solid polymer electrolyte necessitates the use of noble metal catalysts and costly materials of construction. Development work is directed toward reducing the thickness of the solid polymer electrolyte to improve efficiency without excessive gas permeation which reduces Faradaic yield; to achieving successful operation with lower levels of platinum catalyst loading and to seeking lower cost materials of construction.

The other significant research direction is toward electrolysis of water vapour, at temperatures to 1000°C. Major efforts are under way in Germany, Japan, France, the United States and the Soviet Union. The electrolyte in this case is a solid ceramic oxide. Work is at the small unit level but progress is being made; it will however be some years before industrial systems of this type can be made available. The advantage of high temperature electrolysis is in power consumption. At the high temperatures, the thermodynamic reversible voltage is considerably reduced (to 0.8 volts). Operation at reasonable current density (but on a small scale) has been achieved at 1.33 volts DC.

At this point, it might help to summarize the status of each efficiency and present an example of operating cost.

TABLE 1

ELECTROLYSIS EFFICIENCIES

	<u>V_{Cell}</u>	<u>Efficiency (Electrical)</u>	<u>kWh per Nm³</u>
Conventional Electrolysers (70°C without activation)	2.1	71%	5.0
EI-250 Electrolyser (70°C with activation)	1.85	81%	4.4
Thermoneutral Voltage (100% efficiency)	1.5	100%	3.6
Vapour Phase Electrolysis (1000°C) (Note: external heat required)	1.33	100%+	3.3
Power Consumption Range of Practical Cells	4.2 to 4.5 kWh/Nm ³		

26/26

The cost of the electrolytic hydrogen is highly site specific, depending upon the cost of electric power and whether there is a use for the byproduct oxygen. Heavy water is also recoverable byproduct by electrolysis and the value is indicated in this schedule:

TABLE 2
COST OF ELECTROLYTIC HYDROGEN

<u>Electrolysis Operating Cost (Large Plant)</u>	<u>¢ per Nm³</u>
Power - 4.4 kWh (assumed at 3¢ per kWh)	13.2
Costs other than power and capital related (labour, feedwater and maintenance)	<u>0.7</u>
Total Production Cost	13.9
Capital Related Costs	<u>4.0</u>
Total	17.9
<u>Potential By-product Credits</u>	
Sale of oxygen @ \$50/ton	3.9
Recovery of heavy water (net)	<u>2.3</u>
Net Electrolytic Hydrogen Cost	11.9

In conclusion, I have tried to show electrolysis is ready to be the "tomorrow technology", and that further improvements are ahead.

Thank you.

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It is now apparent that the U.S. cannot agree to any international "compromise" on Global Warming that would be acceptable to Europe or the domestic media, without triggering wholly unacceptable domestic legislation. Accordingly, we believe that to avoid the domestic legislation risk, you should begin now to mount a public diplomacy initiative, perhaps building on your Houston 1990 Forests initiative, in order to blunt the adverse publicity that will almost certainly result from a perceived "failure" on Global Warming and in order to take the high ground on issues of real environmental concern.

The immediate problem is a domestic one: no matter how vaguely worded the U.S. international commitment to limiting greenhouse gas emissions might be, it now appears virtually certain that the EC and the U.S. media will establish "stabilization" of CO2 emissions as the litmus test for a success at Rio. Yet, the mere use of the word "stabilization" will trigger immediate adoption of already pending legislation which will impose rigid and economically intolerable regulations as a matter of U.S. domestic law.

That legislation is the so called Waxman bill, which would require an immediate regulatory response to stabilize U.S. CO2 emissions at 1990 levels by the year 2000, and thereafter cap those emissions at that level. There is no provision for key flexibilities the U.S. has urged, such as trading between CO2 and other greenhouse gases (such as methane) or tree-planting to absorb CO2. Nor is there any provision for trading between countries (that would, for example, permit the U.S. to purchase CO2 reductions from China at say \$50/ton, as opposed to imposing them in this country at say \$500/ton).

You should be aware that enormous effort has gone into persuading the OECD and the G-77 to accept principles developed by you in the Clean Air Act that permit market incentive trading, both across gases and across countries, in order to reduce dramatically the cost of complying with the cost of pollution reductions.

You should also be aware that equal amount of time has been spent persuading European allies that we should not commit now internationally to firm targets and timetables for CO2 reductions because of the potential economic disruption that would be caused, even assuming adoption of flexible trading provisions.

Both efforts, however, will vanish instantly once a vote is taken on the Waxman amendment, which will put us in a CO2 straightjacket applicable to no other country. (In Europe, signing an international CO2 stabilization agreement will not translate into a regulatory/litigation bonanza, nor into as high

costs as in the U.S., and the Europeans know it. That is one reason they resist the cost-cutting flexibility we have urged.)

On the other hand, we believe that the U.S. cannot stand firm on the Global Warming agreement - and that you certainly cannot go to Rio in that event - unless the U.S. mounts a public diplomacy "counterattack" on Europe and the G-77 for letting the Forests effort collapse.

Forests are a huge part of Global Warming: rain forest burning contributes 15-30% of global CO2 emissions annually, and forests are 1/2 of the total CO2 sink. Moreover, rain forest destruction presents a far more immediate problem than Global Warming. Whereas we have a decade or more to react to Global Warming if additional science research demonstrates its reality, most of our rain forests may disappear within that time period. Today they are being destroyed at 42 million acres a year - 50% faster than in 1980. In addition to storing CO2, these forests harbor vast and irreplaceable biodiversity that sustains life and could hold the key to cures for many diseases.

The Forests issue has been frustrated by most of the advanced nations because under a fair investment strategy, those wealthy countries with no forests (the Japanese, Saudis and Dutch, for example) would have to make a relatively greater contribution to the LDCs than the U.S., Canada or Russia would. The forest-rich, mostly less-developed countries, have understandably taken a walk because they perceive a forest agreement as constraining their economies and sovereignty. In the absence of any pressure on this issue, the result is an almost global ganging-up on the U.S. under the Global Warming umbrella.

Yet saving the forests could be pursued through a bilateral investment strategy that does not require a new central fund and does not press the LDCs to forfeit their sovereignty. Moreover, saving the forests need not break the bank -- the cost is dramatically lower, for far more environmental benefits, than stopping U.S. CO2 emissions. Estimates of the cost to stabilize CO2 emissions on the EC or Waxman plans run around 1-3% of GNP per year - a \$50-\$150 billion annual cost to the U.S., for virtually no change in global emissions (since LDCs are the major sources of increasing emissions) and only hypothetical benefits. The cost to stabilize deforestation now, by contrast, is estimated at a world total of around \$5 billion per year, and would prevent significant new CO2 emissions. If, for the sake of comparison, the U.S. were to propose doubling current world forests assistance of \$1.35 billion to \$2.7 billion, and if we pledged 20% or \$540 million for our share, we would be spending only \$200 million more than our current international forests budget of \$350 million - in return for real, immediate benefits, both environmental and political.

There is absolutely no reason, however, for you or the U.S. to be in a defensive posture internationally on the environment. You personally are responsible for virtually all of the recent international environmental advances (i.e., CFC and lead phase out; alternative, clean fuel development; introduction of market-based principles in the Clean Air Act; etc.). The U.S. leads Europe in virtually every area of environmental protection -- air pollution, water pollution, etc. For example, the U.S. is ten years ahead of Europe in phasing lead out of gasoline; the U.S. is 42% ahead of the Montreal Protocol schedule, and 20% ahead of Europe, in phasing out CFCs - not even counting your recent acceleration of the U.S. phaseout to 1995. And your call to reduce EC agricultural subsidies in the GATT would markedly reduce the environmental burden of chemical use that these subsidies impose on lands, air and waters - which are five to ten times higher in Europe than in the U.S. In these circumstances, it is criminal to let the criticism of the U.S. go unanswered even if the press will predictably try to pay no attention. Reinvigorating your 1990 Forests initiative could spearhead that answer.