COMMONWEALTH OF MASSACHUSETTS

SUFFOLK, ss.		SUPERIOR COURT CIVIL ACTION NO.: 1984-CV-03333-BLS1
COMMONWEALTH OF MASSACHUSETTS, Plaintiff, v. EXXON MOBIL CORPORATION, Defendant.	)	

AFFIDAVIT OF JUSTIN ANDERSON

I, Justin Anderson, declare and state as follows:

1. I am a partner with the law firm Paul, Weiss, Rifkind, Wharton & Garrison LLP. I am counsel of record for Defendant Exxon Mobil Corporation ("ExxonMobil") in this matter.

2. I submit this affidavit in support of ExxonMobil's Motion to Dismiss the Amended Complaint. I have personal knowledge of the facts stated herein, based on my experience or my consultation with others, or they are known to me in my capacity as counsel for ExxonMobil.

3. Attached to this affidavit as Exhibit A is a copy of a memorandum from Henry Shaw to T. K. Kett regarding "the 'CO_2 Greenhouse Effect,'" dated December 18, 1980. It was obtained from https://insideclimatenews.org/wp-content/uploads/2015/09/Technological-Forecast-on-CO2-Greenhouse-Effect-1980.pdf, and is selectively quoted in paragraphs 84–87 of the Amended Complaint. The Attorney General cites this document for the proposition that "ExxonMobil knew the dangerous effects of [global] warming, resulting from increasing use of fossil fuels, on the global ecosystem, and described the impacts variously as 'dramatic'; akin to

other existential threats to human survival such as 'nuclear holocaust or world famine.'" (Opp. 2–3 (citing Am. Compl. ¶¶ 85–86).)

4. In the Attorney General's discussion of Exhibit A, it omits the following passages from the memorandum that contradict the Attorney General's representations about the document's meaning and significance:

a. "In terms of the societal and institutional responses to an increase in CO2, it was felt that society can adapt to the increase in CO2 and that this problem is not as significant to mankind as a nuclear holocaust or world famine. Finally, in an analysis of the issues associated with economic and geopolitical consequences, it was felt that society can adapt to a CO2 increase within economic constraints that will be existing at the time. Some adaptive measures that were tested, for example, would not consume more than a few percent of the gross national product estimated in the middle of the next century." (Ex. A at 5.) This language is attributed to an "AAAS-DOE sponsored workshop." (Ex. A at 4)

b. "The area of climate modeling was recently studied by a committee of the National Research Council, chaired by Jules G. Charney of MIT, and the conclusions are summarized in their booklet titled 'Carbon Dioxide and Climate: A Scientific Assessment.' This National Research Council study concluded that there are major uncertainties in these models in terms of the timing for a doubling of CO2 and the resulting temperature increase." (Ex. A at 3.)

c. "It is anticipated by most scientists that a general consensus will not be reached until such time as a significant temperature increase can be detected above the natural random temperature fluctuations in average global climate." (Ex. A at 5.)

5. Attached to this affidavit as Exhibit B is a copy of a memorandum from R. W. Cohen to W. Glass, dated August 18, 1981. This document, which was obtained from

https://corporate.exxonmobil.com/-/media/Global/Files/climate-change/media-reported-documents/10_Catastrophic-Effects-Letter-1981_2.pdf, was previously filed by the Attorney General on August 8, 2016, in its Appendix in Opposition to the Petition of ExxonMobil to Set Aside or Modify the Civil Investigative Demand or Issue a Protective Order and in Support of the Commonwealth's Cross-Motion to Compel Exxon to Comply with Civil Investigative Demand No. 2016-EPD-36 ("Investigative Appendix"), and is selectively quoted in paragraphs 11 and 96 of the Amended Complaint. The Attorney General relies on this document for the proposition that "ExxonMobil knew the dangerous effects of [global] warming, resulting from increasing use of fossil fuels, on the global ecosystem, and described the impacts variously as . . . possibly 'catastrophic' for a 'substantial fraction of the earth's population.'" (Opp. 2–3 (citing Am. Compl. ¶ 96).)

6. In the Attorney General's discussion of Exhibit B, it omits the following language from the memorandum that contradicts the Attorney General's representations about the document's meaning and significance: "[O]ur best guess is that observable effects in the year 2030 are likely to be 'well short of catastrophic.'" (Ex. B at 1.)

7. Attached to this affidavit as Exhibit C is a copy of a letter from Roger W. Cohen to A. M. Natkin, dated September 2, 1982. This document, which was obtained from https://corporate.exxonmobil.com/-/media/Global/Files/climate-change/media-reported-documents/11_Consensus-on-CO2-Impacts-1982.pdf, was previously filed by the Attorney General in its Investigative Appendix, and is selectively quoted in paragraphs 99–102 and 120 of the Amended Complaint. The Attorney General relies on this document for the propositions that "ExxonMobil . . . understood the risks climate change poses to its business" (Opp. 3 (citing Am. Compl. ¶ 101), and that "as early as 1982, ExxonMobil concluded that there was a 'clear scientific

consensus,' with which its own research agreed, that a doubling of atmospheric carbon from pre-industrial levels 'would result in an average global temperature rise' of 2.7 to 8.1 degrees Fahrenheit" (Opp. 2 (citing Am. Compl. ¶ 99)).

8. The Attorney General represents that ExxonMobil discussed climate-related risks to its business in this document, when it did not. In addition, in its discussion of Exhibit C, the Attorney General omits the following passages that contradict the Attorney General's representations about the document's meaning and significance:

a. "It should be emphasized that the consensus prediction of global warming is not unanimous. Several scientists have taken positions that openly question the validity of the predictions of the models, and a few have proposed mechanisms which could mitigate a CO_2 warming." (Ex. C at 2.)

b. "The concerns surrounding the possible effects of increased CO_2 have been based on the predictions of models which simulate the earth's climate. These models vary widely in the level of detail in which climate processes are treated and in the approximations used to describe the complexities of these processes. Consequently the quantitative predictions derived from the various models show considerable variation." (Ex. C at 1.)

9. Attached to this affidavit as Exhibit D is a copy of a memorandum from M. B. Glaser, Manager, Environmental Affairs Programs, Exxon Research and Engineering Company, dated November 12, 1982, regarding the "CO_2 'Greenhouse' Effect." This document, which was obtained from https://insideclimatenews.org/wp-content/uploads/2015/09/1982-Exxon-Primer-on-CO2-Greenhouse-Effect.pdf, was previously filed by the Attorney General in its Investigative Appendix, and is selectively quoted in paragraphs 105 to 108 of the Amended Complaint. The Attorney General relies on this document for the proposition that "ExxonMobil knew decades ago

that 'major reductions' in fossil fuel use would be required to mitigate those climate change effects," and "ExxonMobil knew that, once measurable, these effects 'might not be reversible.'" (Opp. 3 (citing Am. Compl. ¶¶ 107–08).)

10. In the Attorney General's discussion of Exhibit D, it omits following passages from the memorandum that contradict the Attorney General's representations about the document's meaning and significance:

a. "Overall, the current outlook suggests potentially serious climate problems are not likely to occur until the late 21st century or perhaps beyond at projected energy demand rates. This should provide time to resolve uncertainties regarding the overall carbon cycle and the contribution of fossil fuel combustion as well as the role of the oceans as a reservoir for both heat and carbon dioxide. It should also allow time to better define the effect of carbon dioxide and other infrared absorbing gases on surface climate. Making significant changes in energy consumption patterns now to deal with this potential problem and all the scientific uncertainties would be premature in view of the severe impact such moves could have on the world's economies and societies." (Ex. D at 5.)

b. "There is currently no unambiguous scientific evidence that the earth is warming." (Ex. D at 4.)

c. "Considerable uncertainty also surrounds the possible impact on society of such a warming trend, should it occur." (Ex. D at 4.)

d. "Fossil fuel combustion and the clearing of virgin forests (deforestation) are believed to be the primary anthropogenic contributors although the relative contribution of each is uncertain." (Ex. D at 4.)

e. "Key points needing better definition include the impact of fossil fuel combustion and the role of the oceans in the carbon cycle and the interactive effect of carbon dioxide and other trace atmospheric gases on climate." (Ex. D at 36.)

f. "Given the long term nature of the potential problem and the uncertainties involved, it would appear that there is time for further study and monitoring before specific actions need be taken." (Ex. D at 36.)

11. Attached to this affidavit as Exhibit E is a copy of a memorandum from Henry Shaw to D. E. Smiley, dated December 5, 1980, regarding H. Shaw's "comments to the [National Commission on Air Quality]." It was obtained from https://insideclimatenews.org/wp-content/uploads/2015/10/Exxons-Policy-Input-to-Congressional-Commission-1980.pdf, and is selectively quoted in paragraphs 92 to 93 of the Amended Complaint. The Attorney General relies on this document for the following proposition: "ExxonMobil knew that . . . if action to address climate change were delayed until effects were measurable, it likely would 'occur too late to be effective.'" (Opp. 3 (citing Am. Compl. ¶ 92).)

12. In its discussion of Exhibit E, the Attorney General omits following passages from the memorandum that contradict the Attorney General's representations about the document's meaning and significance:

a. "[A]ll workshop participants may not necessarily agree with each of the findings and recommendations as expressed below. . . ." (Ex. E at 5.)

b. "At present, there are substantial scientific uncertainties concerning anthropogenic sources of ~~the relationship between human activities,~~ atmospheric ~~levels of~~ carbon dioxide, and their impact on climate and the global environment." (Ex. E at 4 (alterations in original).)

c. “It should be noted, however, that Congressional testimony by key scientific experts in the relevant disciplines dealing with the CO2 question recommended that our energy options not be narrowed at this time.” (Ex. E at 5 (alterations in original).)

13. Attached to this affidavit as Exhibit F is a copy of a presentation by Henry Shaw titled *CO_2 Greenhouse and Climate Issues*, dated March 28, 1984. This document, which was obtained from https://insideclimatenews.org/wp-content/uploads/2015/11/Shaw-Climate-Presentation-1984.pdf, was previously filed by the Attorney General in its Investigative Appendix, and is selectively quoted in paragraphs 109 to 113 and 618 of the Amended Complaint. The Attorney General relies on this document for the proposition that "ExxonMobil has long known that . . . climate change could be ‘avoid[ed] . . . by sharply curtailing’ fossil fuel use.” (Opp. 5 (citing Am. Compl. ¶ 113).)

14. In the Attorney General’s discussion of Exhibit F, it omits the following passages from the presentation that contradict the Attorney General’s representations about the document’s meaning and significance:

a. “The general consensus is that society has sufficient time to technologically adapt to a CO_2 greenhouse effect. Our conclusion was recently reaffirmed by a number of studies which received wide press publicity. These studies include those of the EPA, NRC/NAS, and MIT/NSF.” (Ex. F at 14.)

b. “The time scale for such a catastrophe is measured in centuries.” (Ex. F at 14.)

c. “Our next task is to convert the amou[nt] of CO2 emitted from fossil fuel oxidation into a projection of how it may impact on climate. This, however, requires a number of assumptions.” (Ex. F at 13.)

15. Attached to this affidavit as Exhibit G is a copy of a memorandum from W. L. Ferrall to R. L. Hirsch, dated October 16, 1979, regarding a study prepared by Steve Knisely, a summer employee in the Planning Engineering Division. This document, which was obtained from https://insideclimatenews.org/wp-content/uploads/2015/09/CO2-and-Fuel-Use-Projections.pdf, was previously filed by the Attorney General in its Investigative Appendix, and is selectively quoted in paragraphs 77 to 78 and 80 to 82 of the Amended Complaint. The Attorney General relies on this document for the propositions that "ExxonMobil knew the dangerous effects of such warming, resulting from increasing usage of fossil fuels, on the global ecosystem," and, "ExxonMobil knew decades ago that 'major reductions' in fossil fuel use would be required to mitigate those climate change effects." (Opp. 2–3 (citing Am. Compl. ¶¶ 77, 81–82).)

16. In attributing the statements in Exhibit G to ExxonMobil, the Attorney General does not disclose that the study was the work of a summer intern. In addition, in its discussion of Exhibit G, the Attorney General omits the following passages from the memorandum that undermine its characterization that contradict the Attorney General's representations about the document's meaning and significance:

a. "[I]t is not obvious whether these changes would be all bad or all good." (Ex. G at 1.)

b. "It must be realized that there is great uncertainty in the existing climatic models because of a poor understanding of the atmospheric/terrestrial/oceanic CO_2 balance. Much more study and research in this area is required before major changes in energy type usage could be recommended." (Ex. G at 1.)

c. "[T]he quantitative effect is very speculative because the data base supporting it is weak. The CO_2 balance between the atmosphere, the biosphere and the oceans is very ill-defined. Also, the overall effect of increasing atmospheric CO_2 concentration on the world environment is not well understood. Finally, the relative effect of other impacts on the earth's climate, such as solar activity, volcanic action, etc. may be as great as that of CO_2." (Ex. G at 3.)

d. "[P]redictions of the precise consequences of uncontrolled fossil fuel use cannot be made due to all of the uncertainties associated with the future energy demand and the global CO_2 balance." (Ex. G at 3.)

e. "Too little is known at this time to recommend a major U.S. or worldwide change in energy type usage but it is very clear that immediate research is necessary to better model the atmosphere/terrestrial/oceanic CO_2 balance. Only with a better understanding of the balance will we know if a problem truly exists." (Ex. G at 4.)

Signed under the penalties of perjury, this 11th day of December, 2020.

Justin Anderson
janderson@paulweiss.com
2001 K Street, NW
Washington, D.C. 20006-1047
Tel: (202) 223-7300
Fax: (202) 223-7420

CERTIFICATE OF SERVICE

I, Justin Anderson, counsel for Defendant Exxon Mobil Corporation, hereby certify that on December 15, 2020, I caused a copy of the Affidavit of Justin Anderson and the accompanying exhibits to be served on counsel of record by electronic service in accordance with the Joint Motion to Set Pleading Deadlines, allowed by the Court on April 14, 2020.

/s/ Justin Anderson

Justin Anderson
janderson@paulweiss.com
2001 K Street, NW
Washington, D.C. 20006-1047
Tel: (202) 223-7300
Fax: (202) 223-7420

Exhibit A

GENERAL 7A
MEMORANDUM

CO_2

TO T. K. Kett

FROM HENRY SHAW

DATE December 18, 1980

Attached is the "CO_2 Greenhouse Effect" technological forecast. I have added the items you suggested on 12/16/80. Pat McCall has not had a chance to review this draft. He will contact you directly if he has any comments.

Henry
Henry

HS/lw

Attachment

cc: P. P. McCall
H. C. Hayworth
H. N. Weinberg

H. N. WEINBERG
DEC 30 1980

Ex. A-1

Exxon Research and Engineering Company's Technological Forecast

CO_2 Greenhouse Effect

by

H. Shaw and P. P. McCall

Current Status

The build-up of CO_2 in the atmosphere has been monitored continuously at the National Oceanic and Atmospheric Administration's Observatory at Mauna Loa, Hawaii and periodically in other places since 1957. In addition to observing a trend between 1957-1979 that showed atmospheric CO_2 increasing from 315 to 337 ppm, Keeling and others also observed a seasonal variability ranging from 6 to 10 ppm between a low at the end of summer growing season (due to photosynthesis) and a high at the end of the winter (due to fossil fuel burning for heat, and biomass decay). There is little doubt that these observations indicate a growth of atmospheric CO_2 (See Figure 1). It is also believed that the growth of atmospheric CO_2 has been occuring since the middle of the past century i.e., coincident with the start of the Industrial Revolution. There is, however, great uncertainty on whether the atmospheric CO_2 concentration prior to the Industrial Revolution was 290-300 ppm or 260-270 ppm.

The relative contributions of biomass oxidation (mainly due to deforestation) and fossil fuel combustion to the observed atmospheric CO_2 increase are not known. There are fairly good indications that the annual growth of atmospheric CO_2 is on the order of 2.5 to 3.0 Gt/a of carbon and the net quantity of carbon absorbed by the ocean is similarly 2.5 to 3 Gt/a. Thus, these two sinks (atmosphere and ocean) can account for the total fossil carbon burned which is on the order of 5-6 Gt/a and does not allow much room for a net contribution of biomass carbon. Yet, highly respected scientists, such as Woodwell, Bolin and others have postulated a net biomass contribution to atmospheric CO_2 that range from 1 to perhaps 8 Gt/a of carbon. The rate of forest clearing has been estimated at 0.5 to 1.5%/a of the existing area. Forests occupy about $50 \times 10^6 km^2$ out of about $150 \times 10^6 km^2$ of continental land, and store about 650 Gt of carbon. One can easily see that if 1% of the worlds forests are cleared per year, then this could contribute 6.5 Gt of carbon to the atmosphere. Even if reforestation were contributing significantly to balancing the CO_2 from deforestation, the total carbon stored in new trees would be only a small fraction of the net carbon emitted. It should be noted, however, that the rate of forest clearing and reforestation are not known accurately at this time. If deforestation is indeed contributing to atmospheric CO_2, then another sink for carbon must be found and the impact of fossil fuel must be considered in the context of such a sink.

Ex. A-2

Figure 2, taken out of a recent DOE publication summarizes the fluxes and reserviors for the carbon cycle. Note that a deforestation flux of 0 to 2 Gt/a and a net flux to the oceans of 4 Gt/a are assumed. Thus, the carbon flux to the atmosphere is 6 Gt/a of fossil fuels, and 2 Gt/a deforestation, while 4 Gt/a returned to the ocean resulting in a 50% carbon retention rate in the atmosphere. One of the major objectives of the Exxon Research and Engineering Company project to measure CO_2 in the oceans using tankers is to clarify and quantify the role of the oceans as the ultimate sink for CO_2.

Projections of scientists active in the area indicate that the contribution of deforestation which may have been substantial in the past, will diminish in comparison to the expected rate of fossil fuel combustion in the future. A number of scientists have postulated that a doubling of the amount of carbon dioxide in the atmosphere could occur as early as 2035. Calculations recently completed at Exxon Research indicate that using the energy projections from the CONAES study and the World Energy Conference, a doubling of atmospheric CO_2 can occur at about 2060. If synthetic fuels are not developed, and fossil fuel needs are met by petroleum, then the atmospheric CO_2 doubling time would be delayed by about 5 years to 2065. It is now clear to most people working in the area that the doubling time will be much later in the future that previously postulated because of the decreasing rate of fossil fuel use.

<u>Description of potential impact on weather, climate, and land availability</u>

The most widely accepted calculations carried on thusfar on the potential impact of a doubling of carbon dioxide on climate indicate that an increase in the global average temperature of $3 \pm 1.5^{o}C$ is most likely. Such changes in temperature are expected to occur with uneven geographic distribution, with greater warming occuring at the higher latitudes i.e., the polar regions. This is due to the presumed change in the reflectivity of the Earth due to melting of the ice and snow cover (See Figure 3). There have been other calculations on a more limited scale by a number of climatologists which project average temperature increases on the order of $0.25^{o}C$ for a doubling of CO_2. These calculations are not held in high regard by the scientific community. Figure 4 summarizes the results presented in the literature on the possible temperature increase due to various changes in atmospheric CO_2 concentration.

The area of climate modeling was recently studied by a committee of the National Research Council, chaired by Jules G. Charney of MIT, and the conclusions are summarized in their booklet titled "Carbon Dioxide and Climate: A Scientific Assessment." This National Research Council study concluded that there are major uncertainties in these models in terms of the timing for a doubling of CO_2 and the resulting temperature increase. These uncertainties center around the thermal

Ex. A-3

capacity of the oceans. The oceans have been assumed to consist of a relatively thin, well mixed surface layer averaging about 70 meters in depth in most of the general circulation model, and that the transfer of heat into the deep ocean is essentially infinitely slow. The Charney panel feels, however, that the amount of heat carried by the deep ocean has been underestimated and the oceans will slow the temperature increase due to doubling of atmospheric CO_2. The Charney group estimated that the delay in heating resulting from the effect of the oceans could delay the expected temperature increase due to a doubling of CO_2 by a few decades.

Along with temperature increase, other climatological factors that are expected to occur will include uneven global distribution of increased rainfall, and increased evaporation. These disturbances in the existing global water distribution balance will have dramatic impact on soil moisture, and in turn, on agriculture. The state-of-the-art in climate modeling allows only gross global zoning while some of the expected results from temperature increase of the magnitude indicated are quite dramatic. For example, areas that 4,000 to 8,000 years ago in the Altithermal period (when the global average temperature was some $2^{o}C$ higher than present) were deserts, may in due time return to deserts. Conversely, some areas which are deserts now were formerly agricultural regions. It is postulated that part of the Sahara Desert in Africa was quite wet 4,000 to 8,000 years ago. The American Midwest, on the other hand, was much drier, and it is projected that the Midwest will again become drier should there be a temperature increase of the magnitude postulated for a doubling of atmospheric CO_2 (See Figure 5).

In addition to the effects of climate on the globe, there are some particularly dramatic questions that might cause serious global problems. For example, if the Antartic ice sheet which is anchored on land, should melt, then this could cause a rise in the sea level on the order of 5 meters. Such a rise would cause flooding in much of the U.S. East Coast including the state of Florida and Washington D.C. The melting rate of polar ice is being studied by a number of glaciologists. Estimates range for the melting of the West Antartica ice sheet from hundreds of years to a thousand years.

In a recent AAAS-DOE sponsored workshop on the environmental and societal consequences of a possible CO_2 induced climate change, other factors such as the environmental effects of a CO_2 growth rate on the less managed biosphere were studied. For example, the impact of a temperature increase and a higher atmospheric CO_2 concentration on weeds and pests was considered. The general concensus was that these unmanaged species would tend to thrive with increasing average global temperature. The effects of atmospheric CO_2 growth on the managed biosphere such as in agriculture would also tend to benefit from a CO_2 growth. It turns out that CO_2 can fertilize agriculture, provided the other key nutrients, phosphorous and nitrogen, are present in the right proportions. Agricultural water needs can be met by new irrigation techniques that require less water. In addition, with highest CO_2 and higher temperature conditions, the amount of water that some agricultural plants may need will be reduced. It is expected that bioscience contributions could point the way for dealing with climatological disruptions of the magnitude indicated above.

In terms of the societal and institututional responses to an increase in CO_2, it was felt that society can adapt to the increase in CO_2 and that this problem is not as significant to mankind as a nuclear holocaust or world famine. Finally, in an analysis of the issues associated with economic and geopolitical consequences, it was felt that society can adapt to a CO_2 increase within economic constraints that will be existing at the time. Some adaptive measures that were tested, for example, would not consume more than a few percent of the gross national product estimated in the middle of the next century.

Major Programs Underway

The DOE which is acting as a focal point for the U.S. government in this area is considering two reports to the scientific community and to the policy makers. The first one, summarizing five years of study is due in 1984, and the second one in 1989. The current plan is to spend approximately 10 years of research and assessment prior to recommending policy decisions in this area which impact greatly on the energy needs and scenarios for the U.S. and the world. The national program on CO_2, environment and society is summarized in Figure 6.

Projections on When General Concensus Can be Reached

It is anticipated by most scientists that a general concensus will not be reached until such time as a significant temperature increase can be detected above the natural random temperature fluctuations in average global climate. The earliest that such discreet signals will be able to be measured is after the year 2000. However, depending on the actual global energy demand and supply, it is possible that some of the concerns about CO_2 growth due to fossil fuel combustion will be minimized if fossil fuel use is decreased due to high price, scarcity, and unavailability. Figure 7 illustrates the behavior of the mean global temperature from 1850 to the present contained within an envelope scaled to include the random temperature fluctuations.

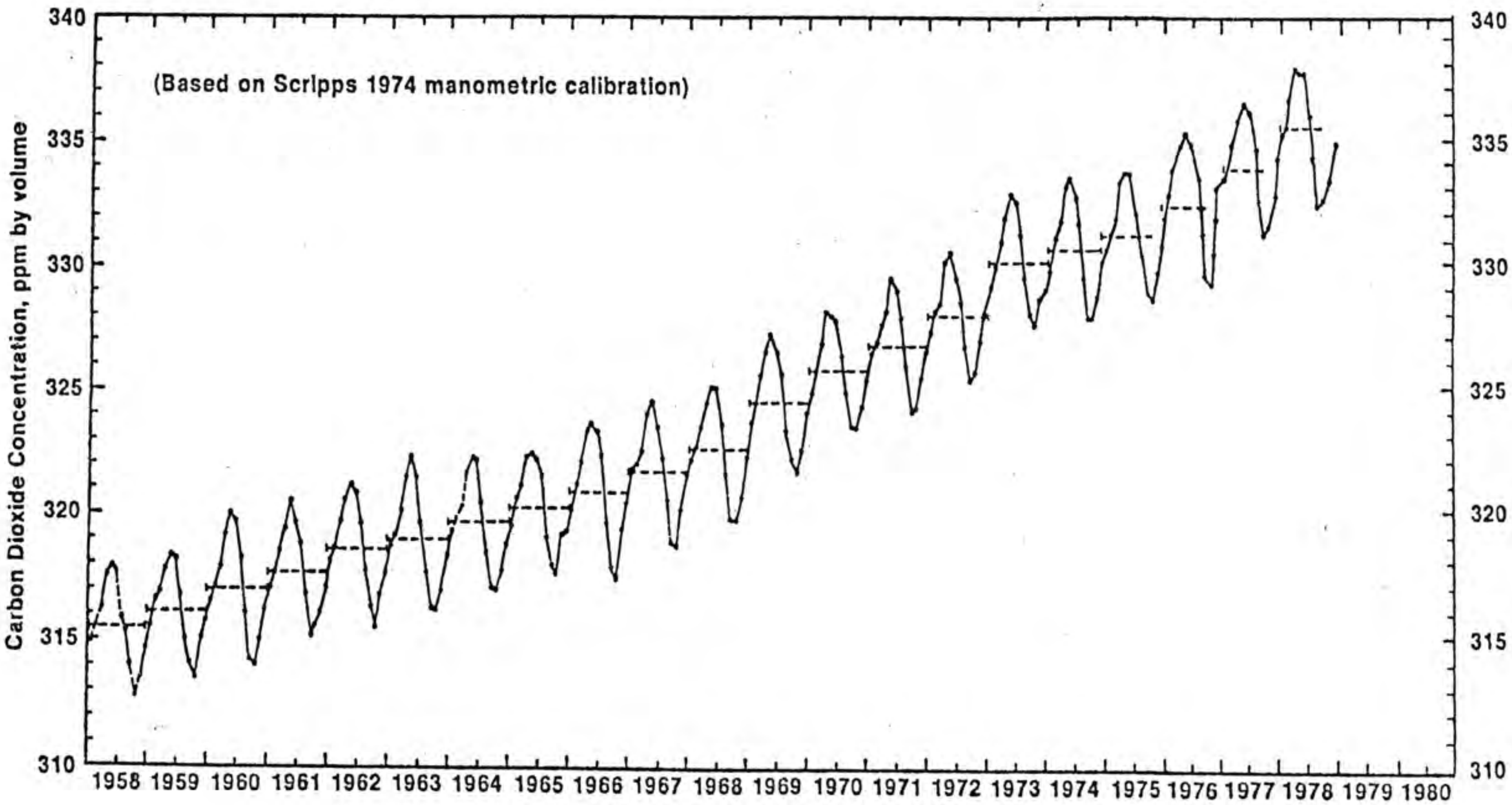
Future Scenarios and Their Consequences For Exxon

A number of future energy scenarios have been studied in relation to the CO_2 problem. These include such unlikely scenarios as stopping all fossil fuel combustion at the 1980 rate, looking at the delay in doubling time and maintaining the pre-1973 fuel growth rate. Other studies have investigated the market penetration of non-fossil fuel technologies such as nuclear, and its impact on CO_2. It should be noted, however, that a new technology in a competitive scenario would need about 50 years to penetrate and achieve roughly half of the total market. Thus, even if solar or nuclear were to be considered viable alternatives, these would not really displace fossil fuel power generation for the next 50 years or so, and CO_2 growth would have to be estimated based on realistic market displacement of the fossil fuel technologies. All of these studies tend to give a range of deviations on the order of 50 years, indicating a CO_2 doubling time that might be as early as 2035 (for a fossil fuel growth rate of 4.3%), to a doubling time occuring by about 2080 resulting from scenarios which assumed fossil fuel growth rates of 1 to 2%. Synthetic fuels will cause minor perturbations on the projected atmospheric CO_2 growth rates in the next century.

Ex. A-6

FIGURE 1

Trend in Atmospheric CO_2 Concentrations at Mauna Loa (Hawaii)

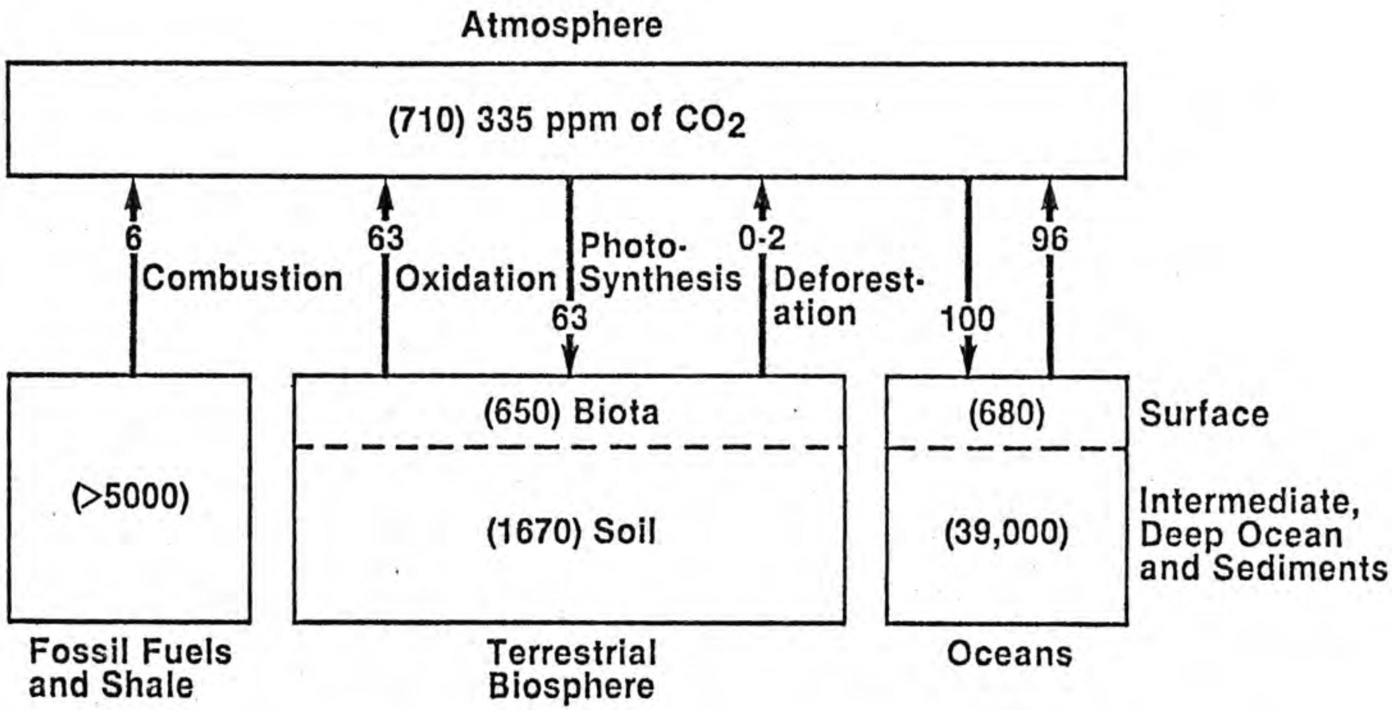


Year

Ex. A-7

FIGURE 2

Exchangeable Carbon Reservoirs and Fluxes



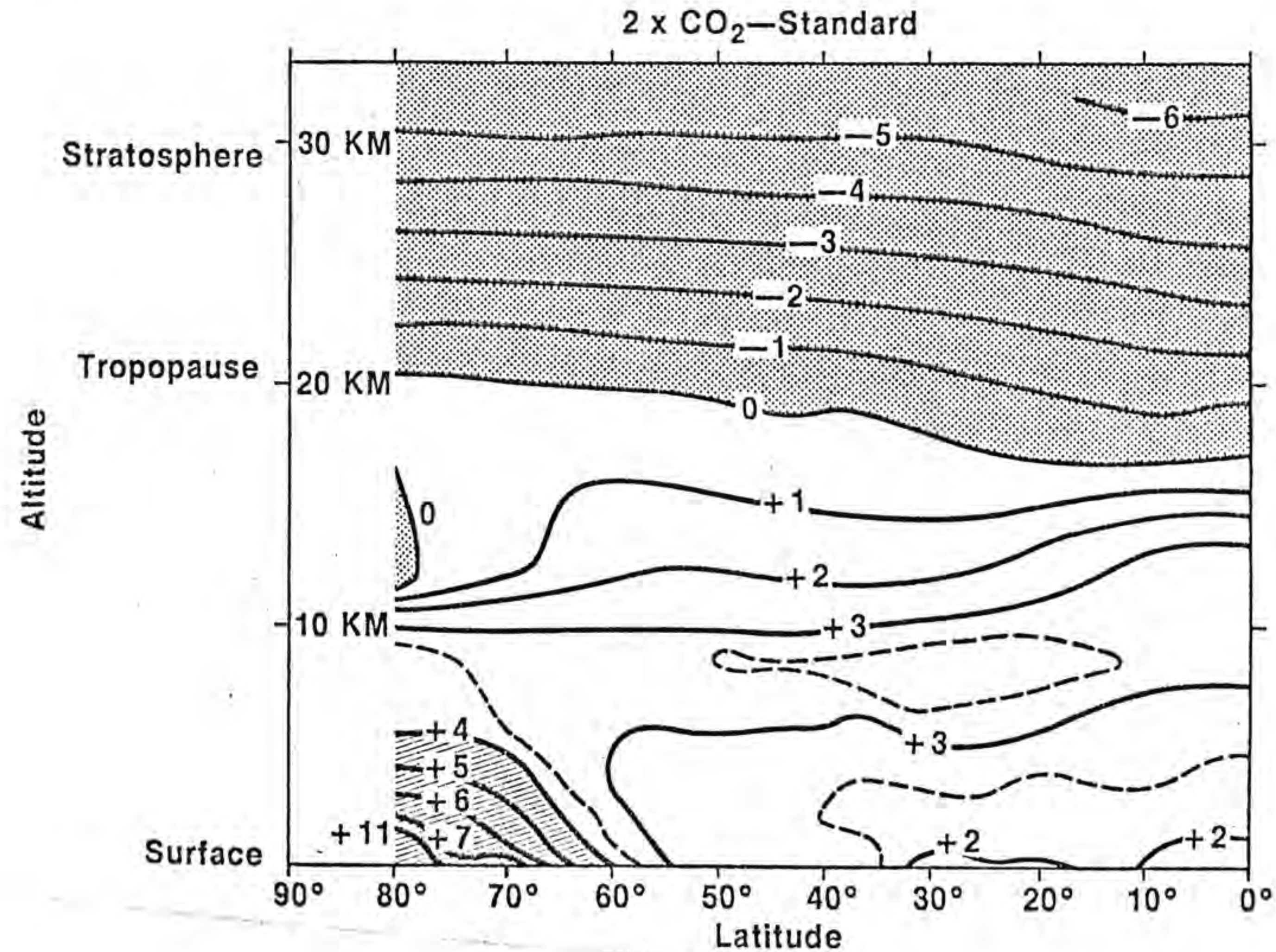
( ) = Size of Carbon Reservoirs in Billions of Metric Tons of Carbon

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

Ex. A-8

FIGURE 3

Temperature Change (^oC) Due to Doubling CO_2 Concentrations



---- Decrease in Temperature

Ex. A-9

FIGURE 4

Estimates of the Change in Global Average Surface Temperature Due to Various Changes in CO_2 Concentration. Shading Shows Present Range of Natural Fluctuations.

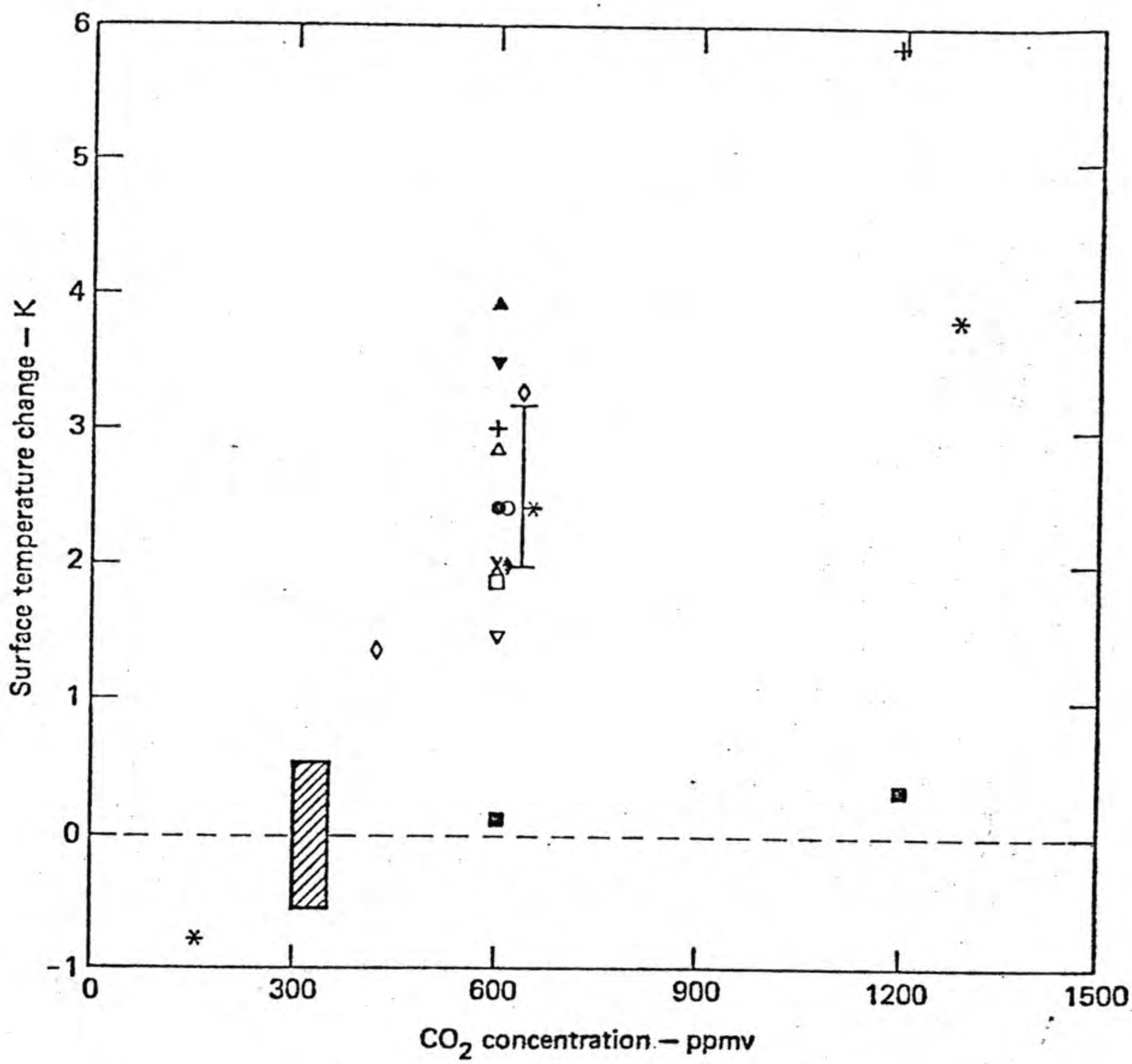
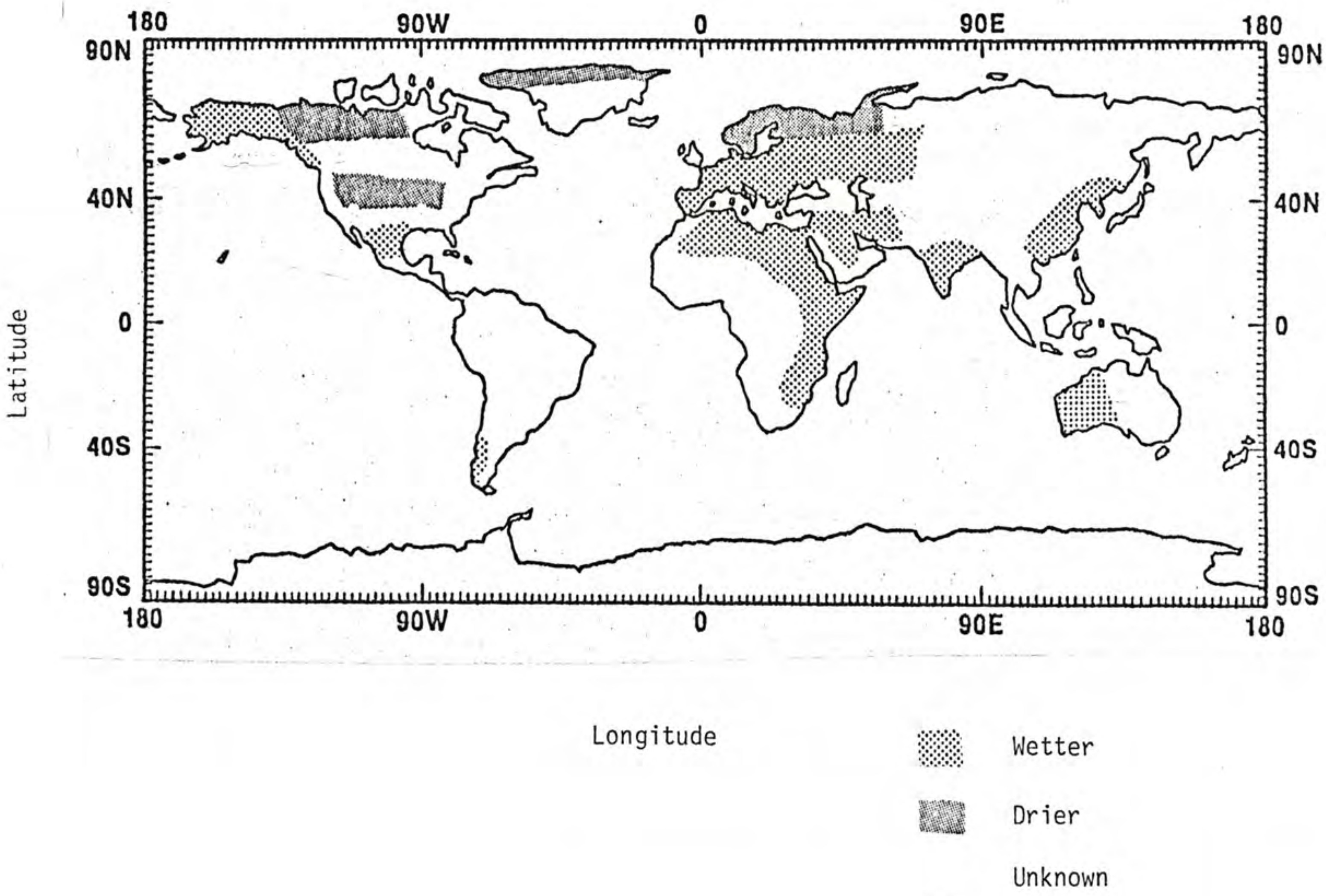


FIGURE 5

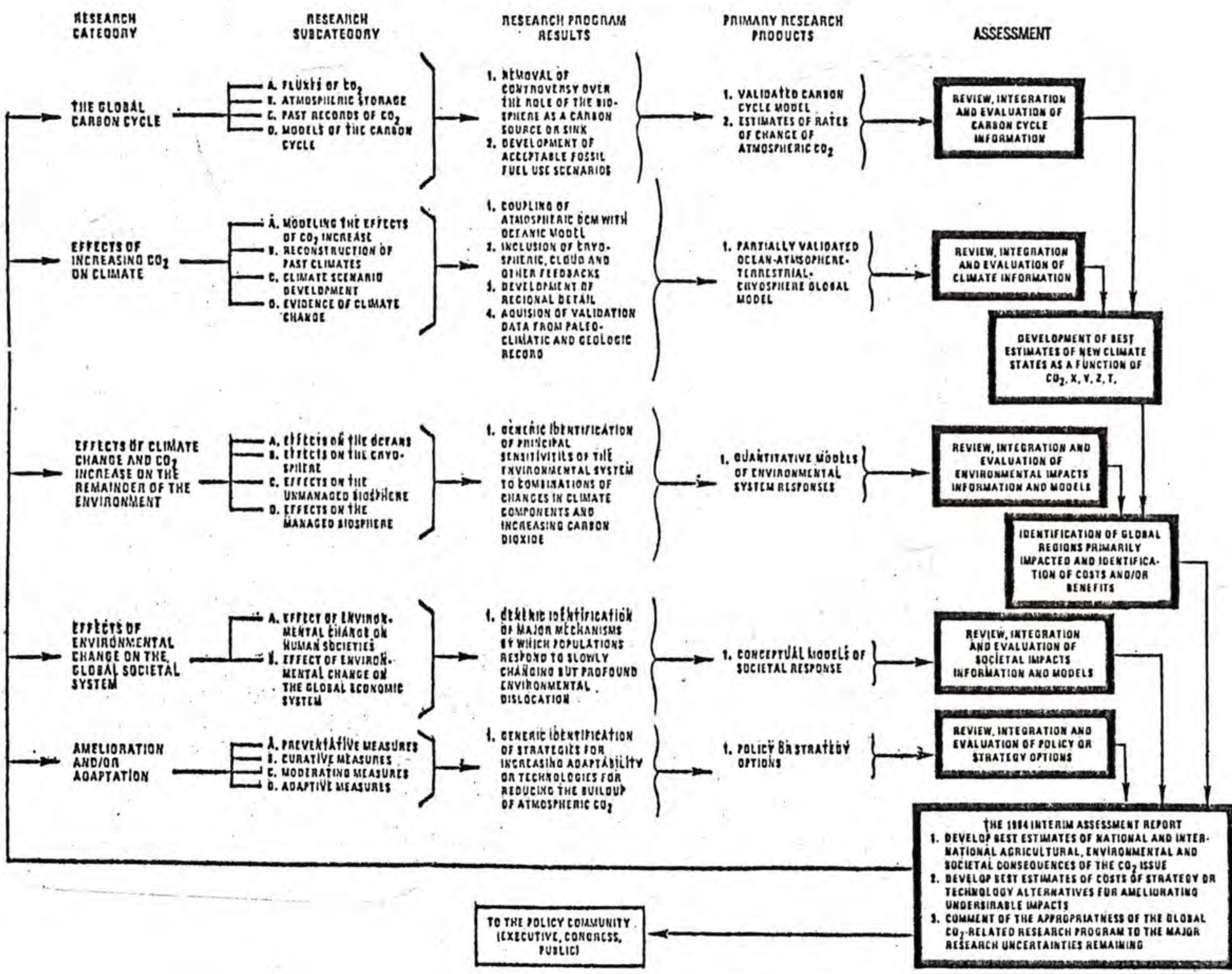
The Altithermal Period



Ex. A-11

FIGURE 6

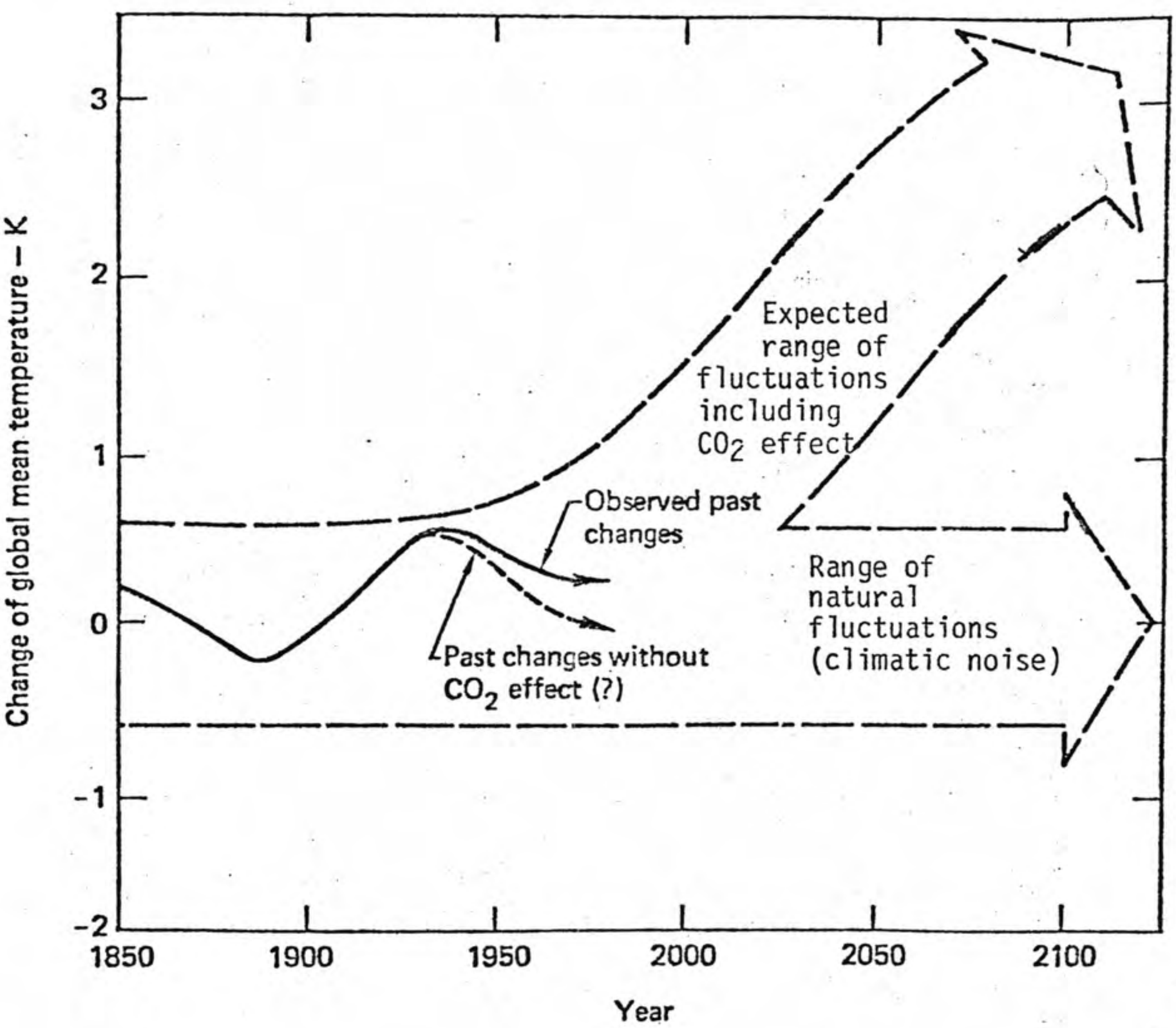
A National Program on Carbon Dioxide, Environment and Society



Ex. A-12

FIGURE 7

Range of Global Mean Temperature From 1850 to the Present with the Projected Instantaneous Climatic Response to Increasing CO_2 Concentrations.



Ex. A-13

Ex. A-14

Exhibit B

ENERAL – 154-1-18

INTER-OFFICE CORRESPONDENCE

DATE August 18, 1981

TO	REFERENCE
W. Glass	SUBJECT
FROM R. W. Cohen	

I have looked over the draft of the EED reply to the request from O'Loughlin. The only real problem I have is with the second clause of the last sentence in the first paragraph: "but changes of a magnitude well short of catastrophic..." I think that this statement may be too reassuring. Whereas I can agree with the statement that our best guess is that observable effects in the year 2030 are likely to be "well short of catastrophic", it is distinctly possible that the CPD scenario will later produce effects which will indeed be catastrophic (at least for a substantial fraction of the earth's population). This is because the global ecosystem in 2030 might still be in a transient, headed for much more significant effects after time lags perhaps of the order of decades. If this indeed turns out to be case, it is very likely that we will unambiguously recognize the threat by the year 2000 because of advances in climate modeling and the beginning of real experimental confirmation of the CO_2 effect. The effects of such a recognition on subsequent fossil fuel combustion are unpredictable, but one can say that predictions based only on our knowledge of availability and economics become hazardous.

I would feel more comfortable if the first paragraph concluded with a statement to the effect that future developments in global data gathering and analysis, along with advances in climate modeling, may provide strong evidence for a delayed CO_2 effect of a truly substantial magnitude, a possibility which increases the uncertainty surrounding the post-2000 CPD scenario.

ROGER W. COHEN

RWC:tmw

Attachment

cc: H. N. Weinberg
A. J. Callegari

Ex. B-1

ENERAL 154-1-1B

TER-OFFICE CORRESPONDENCE

DATE 8/14/81

O See Below	REFERENCE
ROM W. Glass	SUBJECT

J. F. Black
R. W. Cohen
S. A. Diamond
H. Shaw

Morey O'Loughlin has asked Ed David for ER&E's views on the realism of CPD's projections for fossil fuel combustion out to 2030 (attached) in view of potential "greenhouse" and "acid rain" problems. I have been asked to draft a short reply.

A preliminary draft for EED's reply is attached. It is based not on any calculations but on my "understanding" of what I think I've heard you say and write in the past. I would appreciate your reviewing this preliminary draft very critically and letting me know promptly of any changes you would like to see. EED wants to get an answer back to MEJO'L by August 21.

Thank you for your cooperation.

WG:bl
Attachments

c: T. K. Kett

Ex. B-2

DRAFT
EED TO MEJO'L

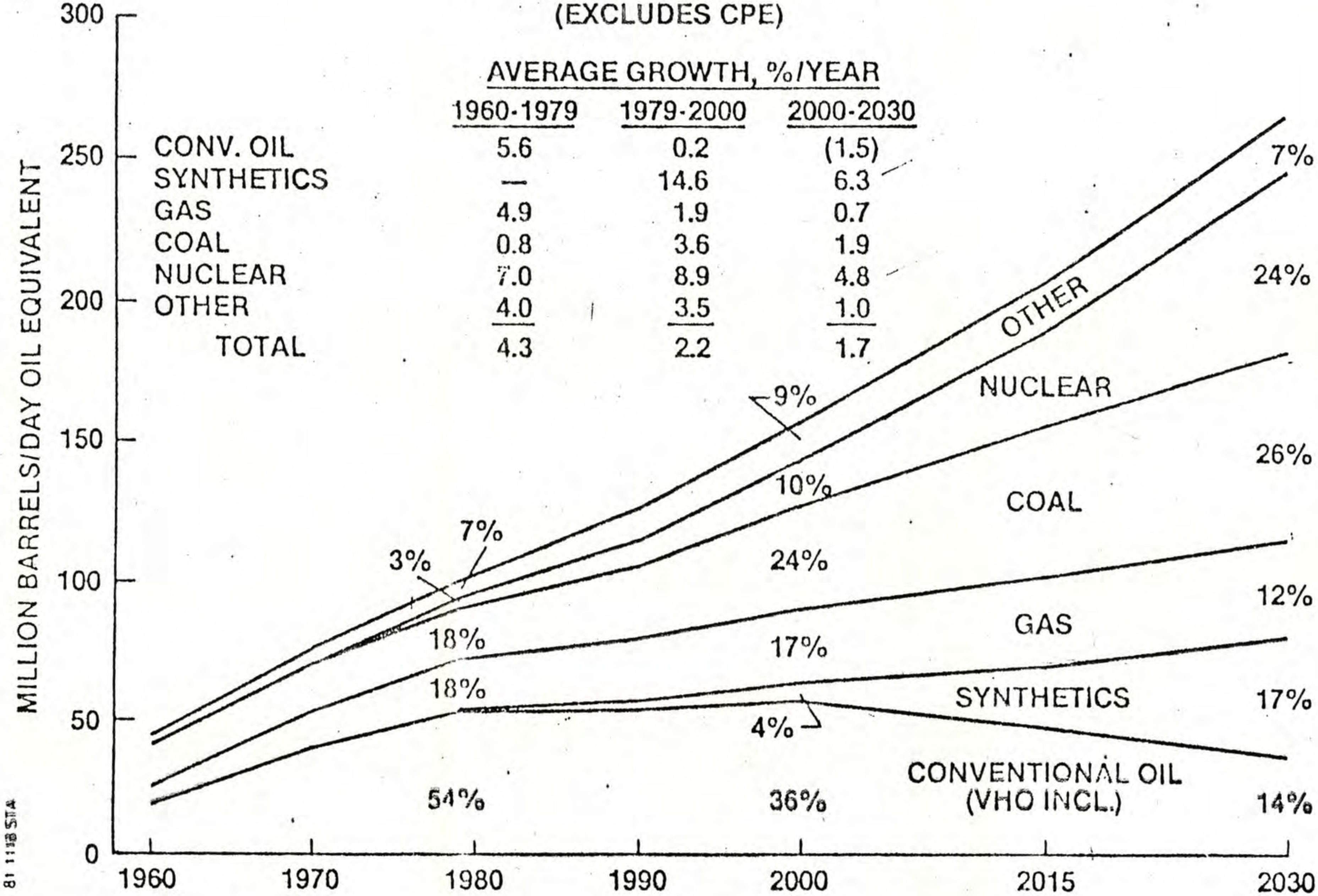
You asked about our views on possible emission consequences of the CPD-projected fossil fuel consumption levels out to 2030. Much is still unknown about the sources and sinks for atmospheric CO_2, as well as about the climatic effect of increasing CO_2 levels in the air, so that prognostications remain highly speculative. The models that appear most credible (to us) do predict measurable changes in temperature, rainfall pattern, and sea-level by the year 2030 for the postulated fossil fuel combustion rates, but changes of a magnitude well short of catastrophic and probably below the magnitude that need trigger otherwise non-economic responses to the problem of energy supply.

The fossil fuel contribution to the localized problem of acid rain appears handlable by limiting the release of SO_x, NO_x, and chlorides to the atmosphere--which would decrease but by no means eliminate the economic advantage of fossil fuels.

We would be happy to discuss this with you in greater detail.

Ex. B-3

INITIAL PROJECTION
WORLD ENERGY SUPPLY
(EXCLUDES CPE)



AVERAGE GROWTH, %/YEAR

	1960-1979	1979-2000	2000-2030
CONV. OIL	5.6	0.2	(1.5)
SYNTHETICS	—	14.6	6.3
GAS	4.9	1.9	0.7
COAL	0.8	3.6	1.9
NUCLEAR	7.0	8.9	4.8
OTHER	4.0	3.5	1.0
TOTAL	4.3	2.2	1.7

Exhibit C

0757-L-RWC

EXXON RESEARCH AND ENGINEERING COMPANY

CORPORATE RESEARCH
SCIENCE LABORATORIES

P. O. Box 45, Linden, N. J. 07036

DUANE G. LEVINE, Director

ROGER W.COHEN, Director
Theoretical and Mathematical Sciences Laboratory

September 2, 1982

H. N. WEINBERG
SEP 2 1982

Mr. A. M. Natkin
Office of Science and Technology
Exxon Corporation
1251 Avenue of the Americas
New York, New York 10020

Dear Al:

I would like to summarize the findings of our research in climate modeling and place our results in the context of the existing body of knowledge of the CO_2 greenhouse effect.

Although the increase of atmospheric CO_2 is well documented, it has not yet resulted in a measurable change in the earth's climate. The concerns surrounding the possible effects of increased CO_2 have been based on the predictions of models which simulate the earth's climate. These models vary widely in the level of detail in which climate processes are treated and in the approximations used to describe the complexities of these processes. Consequently the quantitative predictions derived from the various models show considerable variation. However, over the past several years a clear scientific consensus has emerged regarding the expected climatic effects of increased atmospheric CO_2. The consensus[+] is that a doubling of atmospheric CO_2 from its pre-industrial revolution value would result in an average global temperature rise of $(3.0 \pm 1.5)^{\circ}C$. The uncertainty in this figure is a result of the inability of even the most elaborate models to simulate climate in a totally realistic manner. The temperature rise is predicted to be distributed nonuniformly over the earth, with above-average temperature elevations in the polar regions and relatively small increases near the equator. There is unanimous agreement in the scientific community that a temperature increase of this magnitude would bring about significant changes in the earth's climate, including rainfall distribution and alterations in the biosphere. The time

[+]National Research Council Panel Report, Carbon Dioxide and Climate: A Second Assessment, National Academy Press, Washington, D.C., 1982.

Ex. C-1

required for doubling of atmospheric CO_2 depends on future world consumption of fossil fuels. Current projections indicate that doubling will occur sometime in the latter half of the 21st century. The models predict that CO_2-induced climate changes should be observable well before doubling. It is generally believed that the first unambiguous CO_2-induced temperature increase will not be observable until around the year 2000.

It should be emphasized that the consensus prediction of global warming is not unanimous. Several scientists have taken positions that openly question the validity of the predictions of the models, and a few have proposed mechanisms which could mitigate a CO_2 warming. One of the most serious of these proposals has been made by Professor Reginald Newell of MIT. Newell noted that geological evidence points to a relative constancy of the temperature of the equatorial waters over hundreds of millions of years. This constancy is remarkable in view of major climatic changes in other regions of the earth during this period. Newell ascribed this anchoring of the temperature of the equatorial waters to an evaporative buffering mechanism. In this mechanism, when heating increases at the equator, most of the extra energy induces greater rates of evaporation rather than raising temperatures. Newell proposed that this effect might greatly reduce the global warming effect of increased atmospheric CO_2.

In our climate research we have explored the global effects of Newell's evaporative buffering mechanism using a simple mathematical climate model. Our findings indicate that Newell's effect is indeed an important factor in the earth's climate system. As Newell predicted, evaporative buffering does limit CO_2-induced temperature changes in the equatorial regions. However, we find a compensatingly larger temperature increase in the polar regions, giving a global averaged temperature increase that falls well within the range of the scientific consensus. Our results are consistent with the published predictions of more complex climate models. They are also in agreement with estimates of the global temperature distribution during a certain prehistoric period when the earth was much warmer than today.

In summary, the results of our research are in accord with the scientific consensus on the effect of increased atmospheric CO_2 on climate. Our research appears to reconcile Newell's observations and proposed mechanism with the consensus opinion.

We are now ready to present our research to the scientific community through the usual mechanisms of conference presentations and publications in appropriate journals. I have enclosed a detailed plan for presenting our results.

Ex. C-2

As we discussed in the August 24 meeting, there is the potential for our research to attract the attention of the popular news media because of the connection between Exxon's major business and the role of fossil fuel combustion in contributing to the increase of atmospheric CO_2. Despite the fact that our results are in accord with those of most researchers in the field and are subject to the same uncertainties, it was recognized that it is possible for these results to be distorted or blown out of proportion. Nevertheless the consensus position was that Exxon should continue to conduct scientific research in this area because of its potential importance in affecting future energy scenarios and to provide Exxon with the credentials required to speak with authority in this area. Furthermore our ethical responsibility is to permit the publication of our research in the scientific literature; indeed to do otherwise would be a breach of Exxon's public position and ethical credo on honesty and integrity.

Sincerely yours,

Roger W Cohen

ROGER W. COHEN

RWC:tmc

Enclosure

cc: A. J. Callegari
E. E. David, Jr.
B. P. Flannery
M. B. Glaser
D. G. Levine
P. J. Lucchesi
H. N. Weinberg

Ex. C-3

CO_2 Climate Modeling Research: Timetable for Presentations and Publications

I. Presentations

(1) DOE Sponsored CO_2-CLimate Meeting
September 19-23, 1982 (West Virginia)

(a) Results pertaining to general aspects of the model to be presented in an informal session by our collaborator Professor M. I. Hoffert of NYU. The CO_2 calculations will not be included.

(b) Preprints of the paper [#(1) below] to be distributed at this meeting to general peer comments and discussion.*

(2) Ewing Symposium (Lamont-Doherty/Exxon Foundation Supported)
October 25-27, 1982

(a) Results concerning general aspects of the model and the CO_2 calculations to be presented by B. P. Flannery (CR).

II. Publications

(1) Manuscript developing general aspects of the model to be submitted for publication to the Journal of Geophysical Research, September, 1982.*

(2) Manuscript on CO_2 related model predictions to be submitted in late 1982.

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* Provided formal publication clearance has been granted by this time.

Ex. C-4

Exhibit D

EXXON RESEARCH AND ENGINEERING COMPANY
P.O. BOX 101, FLORHAM PARK, NEW JERSEY 07932

M. B. GLASER
Manager
Environmental Affairs Programs

Cable: ENGREXXON, N.Y.

November 12, 1982

CO_2 "Greenhouse" Effect

82EAP 266

TO: See Distribution List Attached

Attached for your information and guidance is briefing material on the CO_2 "Greenhouse" Effect which is receiving increased attention in both the scientific and popular press as an emerging environmental issue. A brief summary is provided along with a more detailed technical review prepared by CPPD.

The material has been given wide circulation to Exxon management and is intended to familiarize Exxon personnel with the subject. It may be used as a basis for discussing the issue with outsiders as may be appropriate. However, it should be restricted to Exxon personnel and not distributed externally.

Very truly yours,

M. B. Glaser

M. B. GLASER

MBG:rva

Attachments

H. N. WEINBERG
NOV 15 1982

Ex. D-1

Ex. D-2

Distribution List:

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Ex. D-3

SUMMARY

Atmospheric monitoring programs show the level of carbon dioxide in the atmosphere has increased about 8% over the last twenty-five years and now stands at about 340 ppm. This observed increase is believed to be the continuation of a trend which began in the middle of the last century with the start of the Industrial Revolution. Fossil fuel combustion and the clearing of virgin forests (deforestation) are believed to be the primary anthropogenic contributors although the relative contribution of each is uncertain.

The carbon dioxide content of the atmosphere is of concern since it can affect global climate. Carbon dioxide and other trace gases contained in the atmosphere such as water vapor, ozone, methane, carbon monoxide, oxides of nitrogen, etc. absorb part of the infrared rays reradiated by the earth. This increase in absorbed energy warms the atmosphere inducing warming at the earth's surface. This phenomenon is referred to as the "greenhouse effect".

Predictions of the climatological impact of a carbon dioxide induced "greenhouse effect" draw upon various mathematical models to gauge the temperature increase. The scientific community generally discusses the impact in terms of doubling of the current carbon dioxide content in order to get beyond the noise level of the data. We estimate doubling could occur around the year 2090 based upon fossil fuel requirements projected in Exxon's long range energy outlook. The question of which predictions and which models best simulate a carbon dioxide induced climate change is still being debated by the scientific community. Our best estimate is that doubling of the current concentration could increase average global temperature by about 1.3° to 3.1°C. The increase would not be uniform over the earth's surface with the polar caps likely to see temperature increases on the order of 10°C and the equator little, if any, increase.

Considerable uncertainty also surrounds the possible impact on society of such a warming trend, should it occur. At the low end of the predicted temperature range there could be some impact on agricultural growth and rainfall patterns which could be beneficial in some regions and detrimental in others. At the high end, some scientists suggest there could be considerable adverse impact including the flooding of some coastal land masses as a result of a rise in sea level due to melting of the Antarctic ice sheet. Such an effect would not take place until centuries after a 3°C global average temperature increase actually occurred.

There is currently no unambiguous scientific evidence that the earth is warming. If the earth is on a warming trend, we're not likely to detect it before 1995. This is about the earliest projection of when the temperature

might rise the 0.5° needed to get beyond the range of normal temperature fluctuations. On the other hand, if climate modeling uncertainties have exaggerated the temperature rise, it is possible that a carbon dioxide induced "greenhouse effect" may not be detected until 2020 at the earliest.

The "greenhouse effect" is not likely to cause substantial climatic changes until the average global temperature rises at least 1°C above today's levels. This could occur in the second to third quarter of the next century. However, there is concern among some scientific groups that once the effects are measurable, they might not be reversible and little could be done to correct the situation in the short term. Therefore, a number of environmental groups are calling for action now to prevent an undesirable future situation from developing.

Mitigation of the "greenhouse effect" would require major reductions in fossil fuel combustion. Shifting between fossil fuels is not a feasible alternative because of limited long-term supply availability for certain fuels although oil does produce about 18% less carbon dioxide per Btu of heat released than coal, and gas about 32% less than oil. The energy outlook suggests synthetic fuels will have a negligible impact at least through the mid 21st century contributing less than 10% of the total carbon dioxide released from fossil fuel combustion by the year 2050. This low level includes the expected contribution from carbonate decomposition which occurs during shale oil recovery and assumes essentially no efficiency improvements in synthetic fuels processes above those currently achievable.

Overall, the current outlook suggests potentially serious climate problems are not likely to occur until the late 21st century or perhaps beyond at projected energy demand rates. This should provide time to resolve uncertainties regarding the overall carbon cycle and the contribution of fossil fuel combustion as well as the role of the oceans as a reservoir for both heat and carbon dioxide. It should also allow time to better define the effect of carbon dioxide and other infrared absorbing gases on surface climate. Making significant changes in energy consumption patterns now to deal with this potential problem amid all the scientific uncertainties would be premature in view of the severe impact such moves could have on the world's economies and societies.

PROPRIETARY INFORMATION

FOR AUTHORIZED COMPANY USE ONLY

CO_2 GREENHOUSE EFFECT

A TECHNICAL REVIEW

PREPARED BY THE

COORDINATION AND PLANNING DIVISION

EXXON RESEARCH AND ENGINEERING COMPANY

APRIL 1, 1982

EC-11-5/A2

Ex. D-6

Ex. D-7

CO_2 GREENHOUSE EFFECT

A TECHNICAL REVIEW

TABLE OF CONTENTS

CO_2 GREENHOUSE EFFECT

Background

The buildup of CO_2 in the atmosphere has been monitored continuously at the National Oceanic and Atmospheric Administration's (NOAA) Observatory at Mauna Loa, Hawaii, and periodically in other places since 1957. In addition to observing a trend between 1957-1979 that showed atmospheric CO_2 increasing from 315 to 337 ppm, Keeling and others also observed a seasonal variability ranging from 6 to 10 ppm between a low at the end of the summer growing season (due to photosynthesis) and a high at the end of winter (due to fossil fuel burning for heat, and biomass decay). There is little doubt that these observations indicate a growth of atmospheric CO_2 (see Figure 1). It is also believed that the growth of atmospheric CO_2 has been occurring since the middle of the past century, i.e., coincident with the start of the Industrial Revolution. There is, however, great uncertainty as to whether the atmospheric CO_2 concentration prior to the Industrial Revolution (ca., 1850) was 290-300 ppm which one would arrive at by assuming atmospheric CO_2 growth is due to fossil fuel burning and cement manufacturing, or 260-270 ppm based on carbon isotope measurements in tree rings. The information on CO_2 concentration prior to 1850 is important because it would help establish the validity of climatic predictions with respect to the inception of a CO_2 induced "greenhouse effect".

The "greenhouse effect" refers to the absorbtion by CO_2 and other trace gases contained in the atmosphere (such as water vapor, ozone, carbon monoxide, oxides of nitrogen, freons, and methane) of part of the infrared radiation which is reradiated by the earth. An increase in absorbed energy via this route would warm the earth's surface causing changes in climate affecting atmospheric and ocean temperatures, rainfall patterns, soil moisture, and over centuries potentially melting the polar ice caps.

Sources and Disposition of Atmospheric Carbon Dioxide - The Carbon Cycle

The relative contributions of biomass oxidation (mainly due to deforestation) and fossil fuel combustion to the observed atmospheric CO_2 increase are not known. There are fairly good indications that the annual growth of atmospheric CO_2 is on the order of 2.5 to 3.0 Gt/a* of carbon and the net quantity of carbon absorbed by the ocean is similarly 2.5 to 3 Gt/a. Thus, these two sinks (atmosphere and ocean) can account for the total fossil carbon burned (including 0.3 GtC/a** from cement manufacturing) which is on the order of 5-6 Gt/a and does not allow much room for a net contribution of biomass

* Gt/a = gigatons per annum = 10^9 metric tons per year.

** GtC/a = gigatons carbon per annum = 10^9 metric tons of carbon per year.

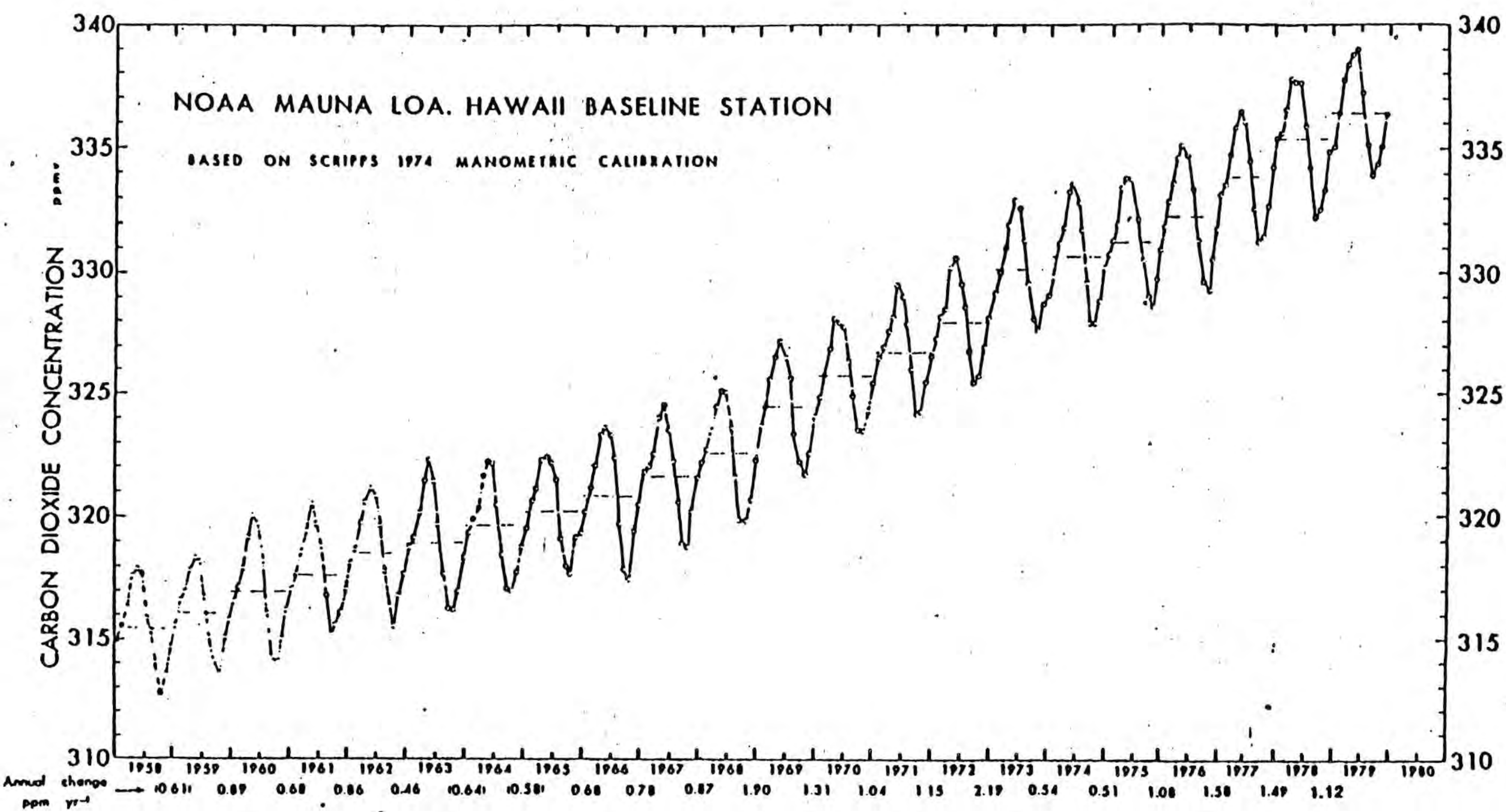


Figure 1 Modern record of atmospheric CO_2 concentrations. Mean monthly concentration measurements at Mauna Loa, Hawaii. Annual changes in parentheses are based on incomplete records; the solid dots are interpolated values (source: NOAA).

Ex. D-10

carbon. Yet, highly respected scientists such as Woodwell, Bolin and others have postulated a net biomass contribution to atmospheric CO_2 that ranges from 1 to perhaps 8 Gt/a of carbon. During 1980, a number of different groups produced new estimates of the contribution of organic terrestial fluxes to atmospheric CO_2. A consensus has not been reached, but estimates of the net annual terrestial biosphere emissions to the atmosphere now range between a 4 GtC/a source and a 2 GtC/a sink. Figure 2 summarizes the fluxes and reservoirs for the carbon cycle. It should be noted that the net biosphere contribution was assumed to be 0-2 GtC/a.

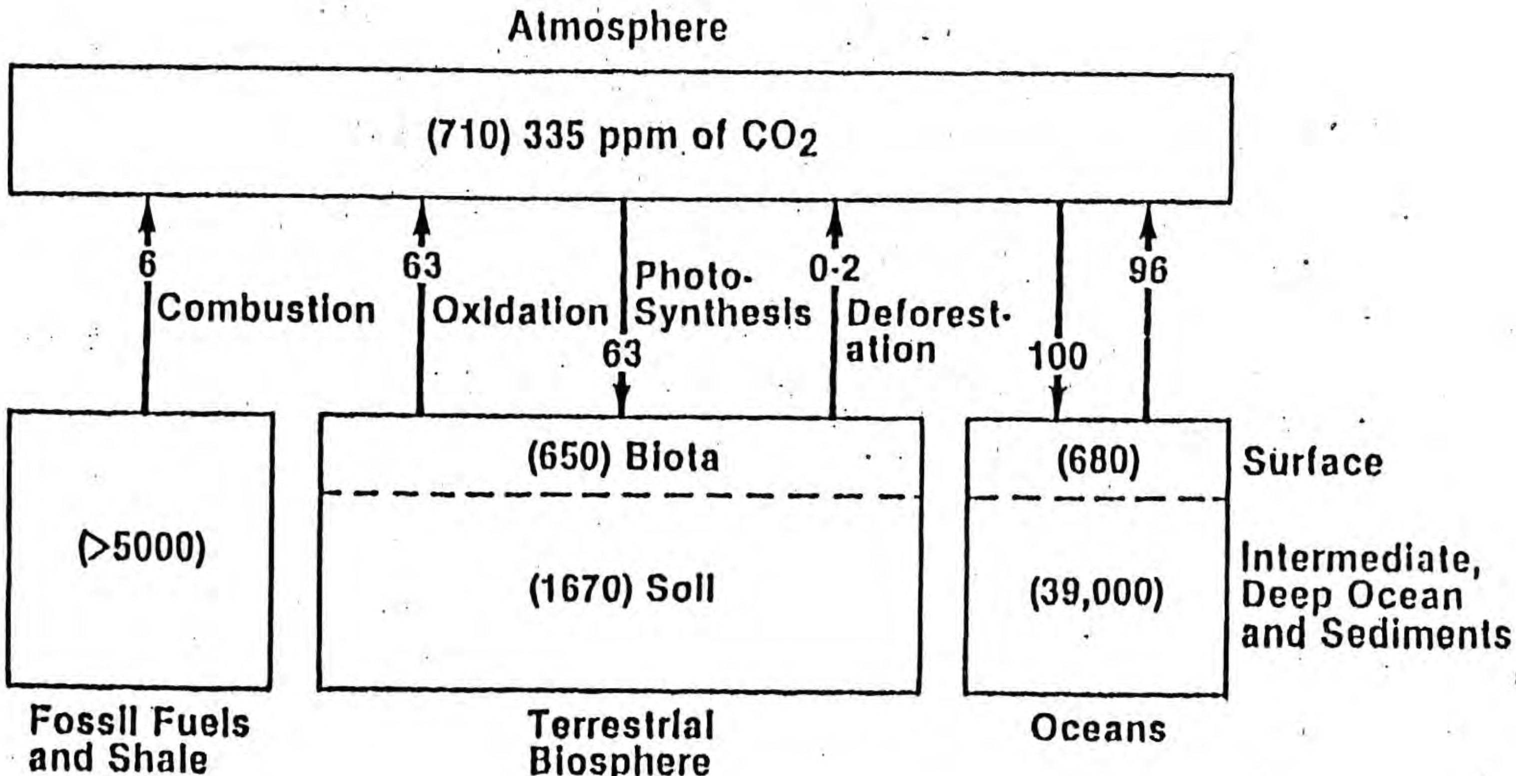
The rate of forest clearing has been estimated at 0.5% to 1.5% per year of the existing area. Forests occupy about 50 x $10^6 km^2$ out of about 150 x $10^6 km^2$ of continental land, and store about 650 Gt of carbon. One can easily see that if 0.5% of the world's forests are cleared per year, this could contribute about 3.0 Gt/a of carbon to the atmosphere. Even if reforestation were contributing significantly to balancing the CO_2 from deforestation, the total carbon stored in new trees tends to be only a small fraction of the net carbon emitted. It should be noted, however, that the rate of forest clearing and reforestation are not known accurately at this time. If deforestation is indeed contributing to atmospheric CO_2, then another sink for carbon must be found, and the impact of fossil fuel must be considered in the context of such a sink.

The magnitude of the carbon fluxes shown in Figure 2 between the atmosphere and the terrestial biosphere, and the atmosphere and the oceans are not precisely known. The flow of carbon between these reservoir pairs is generally assumed to have been in equilibrium prior to the Industrial Revolution. However, the errors in the estimated magnitude of these major fluxes are probably larger than the magnitude of the estimated man-made carbon fluxes, i.e., fossil fuels and deforestation. The man-made fluxes are assumed to be the only ones that have disturbed the equilibrium that is believed to have existed before the Industrial Revolution, and they can be estimated independently of the major fluxes. The man-made carbon fluxes are balanced in Figure 2 between the known growth rate of atmospheric carbon and the oceans. The carbon flux to the atmosphere is 6Gt/a from fossil fuels and cement manufacturing (cement manufacturing contributes about 4% of non-biosphere anthropogenic carbon) and 2Gt/a from deforestation, while 4Gt/a return to the ocean, resulting in a 50% carbon retention rate in the atmosphere. One cannot rule out, in view of the inherent uncertainty of the major fluxes, that the biosphere may be a net sink and the oceans may absorb much less of the man-made CO_2.

Projections of scientists active in the area indicate that the contribution of deforestation, which may have been substantial in the past, will diminish in comparison to the expected rate of fossil fuel combustion in the future. A few years ago a number of scientists hypothesized that a doubling of the amount of carbon dioxide in the atmosphere could occur as early as 2035. This hypothesis is generally not acceptable anymore because of the global curtailment of fossil fuel usage. Calculations recently completed at Exxon Research

FIGURE 2

Exchangeable Carbon Reservoirs and Fluxes



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

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

Ex. D-12

and Engineering Company using the energy projections from the Corporate Planning Department's 21st Century Study*, indicate that a doubling of the 1979 atmospheric CO_2 concentration could occur at about 2090. If synthetic fuels are not developed and fossil fuel needs are met by new gas and petroleum discoveries, then the atmospheric CO_2 doubling time would be delayed by about 5 years to the late 2090's. Figure 3 summarizes the projected growth of atmospheric CO_2 concentration based on the Exxon 21st Century Study-High Growth scenario, as well as an estimate of the average global temperature increase which might then occur above the current temperature. It is now clear that the doubling time will occur much later in the future than previously postulated because of the decreasing rate of fossil fuel usage due to lower demand.

Description of Potential Impact on Weather, Climate, and Land Availability

The most widely accepted calculations carried on thus far on the potential impact on climate of doubling the carbon dioxide content of the atmosphere use general circulation models (GCM). These models indicate that an increase in global average temperature of $3^{\circ} \pm 1.5^{\circ}C$ is most likely. Such changes in temperature are expected to occur with uneven geographic distribution with greater warming occurring at the higher latitudes, i.e., the polar regions. This is due to increased absorption of solar radiation energy on the darker polar surfaces that would become exposed when ice and snow cover melt due to increasing temperature (see Figure 4). There have been other calculations using radiative convective models and energy balance models which project average temperature increases on the order of $0.75^{\circ}C$ for a doubling of CO_2. These calculations are compared in Figure 5. Figure 6 summarizes possible temperature increases due to various changes in atmospheric CO_2 concentration.

If the atmospheric CO_2 content had been 295 ppm prior to the Industrial Revolution, and an average global temperature increase above climate noise is detectable at the present time, this would add credibility to the general circulation models. However, if the CO_2 concentration and been 265 ppm prior to the Industrial Revolution, then detecting a temperature effect of $0.5^{\circ}C$ now would imply that the temperature for a doubling of CO_2 would be $1.9^{\circ}C$. The projected temperatures for both alternatives fall within the $3^{\circ} \pm 1.5^{\circ}C$ range. Temperature projections for alternate scenarios will be discussed later.

Climate modeling was studied by a committee of the National Research Council, chaired by Jules G. Charney of MIT, and the conclusions are summarized in

* The "21st Century Study" referred to here and in other places in this report has been superseded by a new energy study called the "2030 Study". The new study projects energy demands that are lower than the earlier figures, but not sufficiently different to change any of the conclusions of this report.

Figure 3

GROWTH OF ATMOSPHERIC CO_2 AND AVERAGE GLOBAL TEMPERATURE INCREASE AS A FUNCTION OF TIME

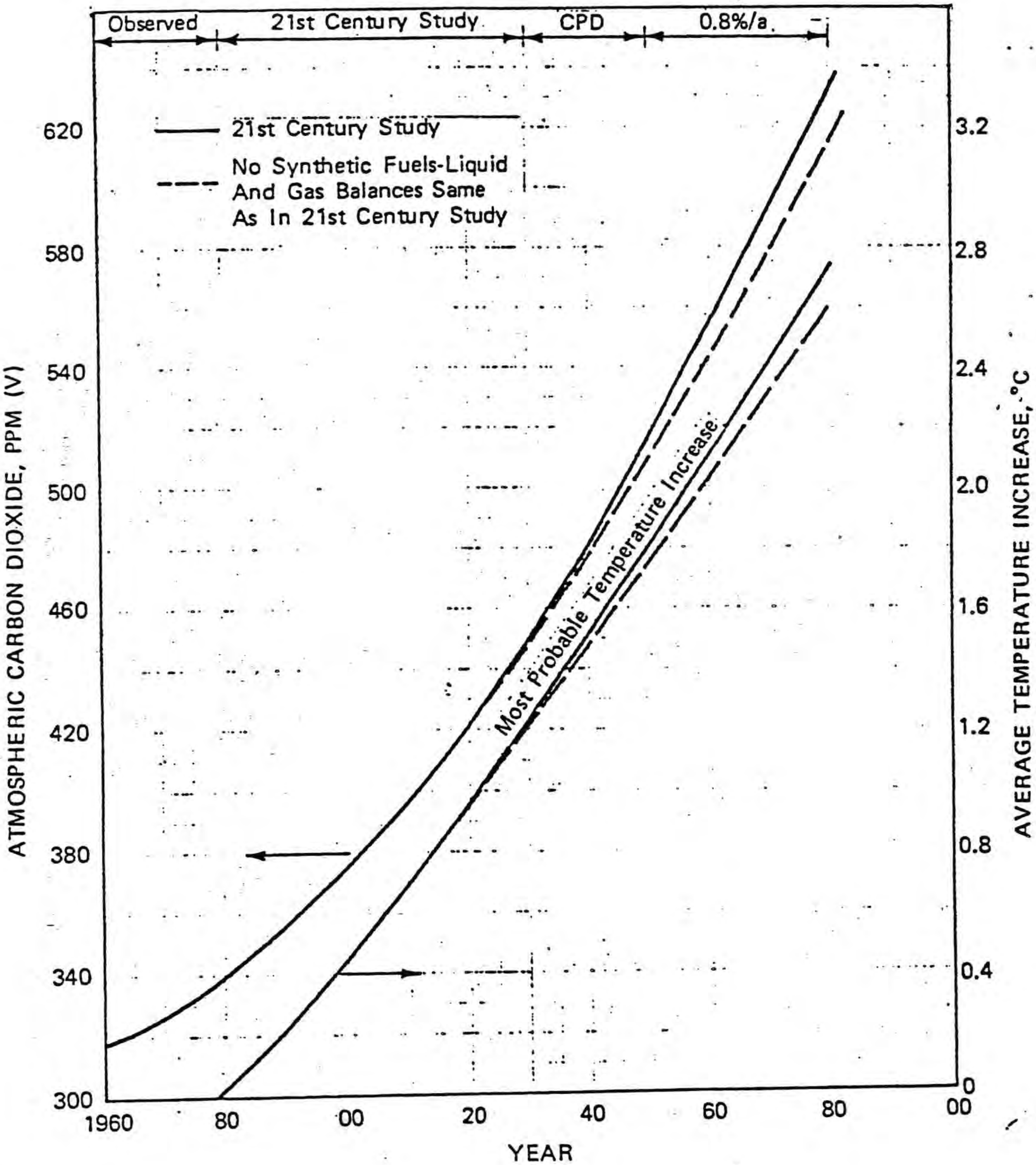
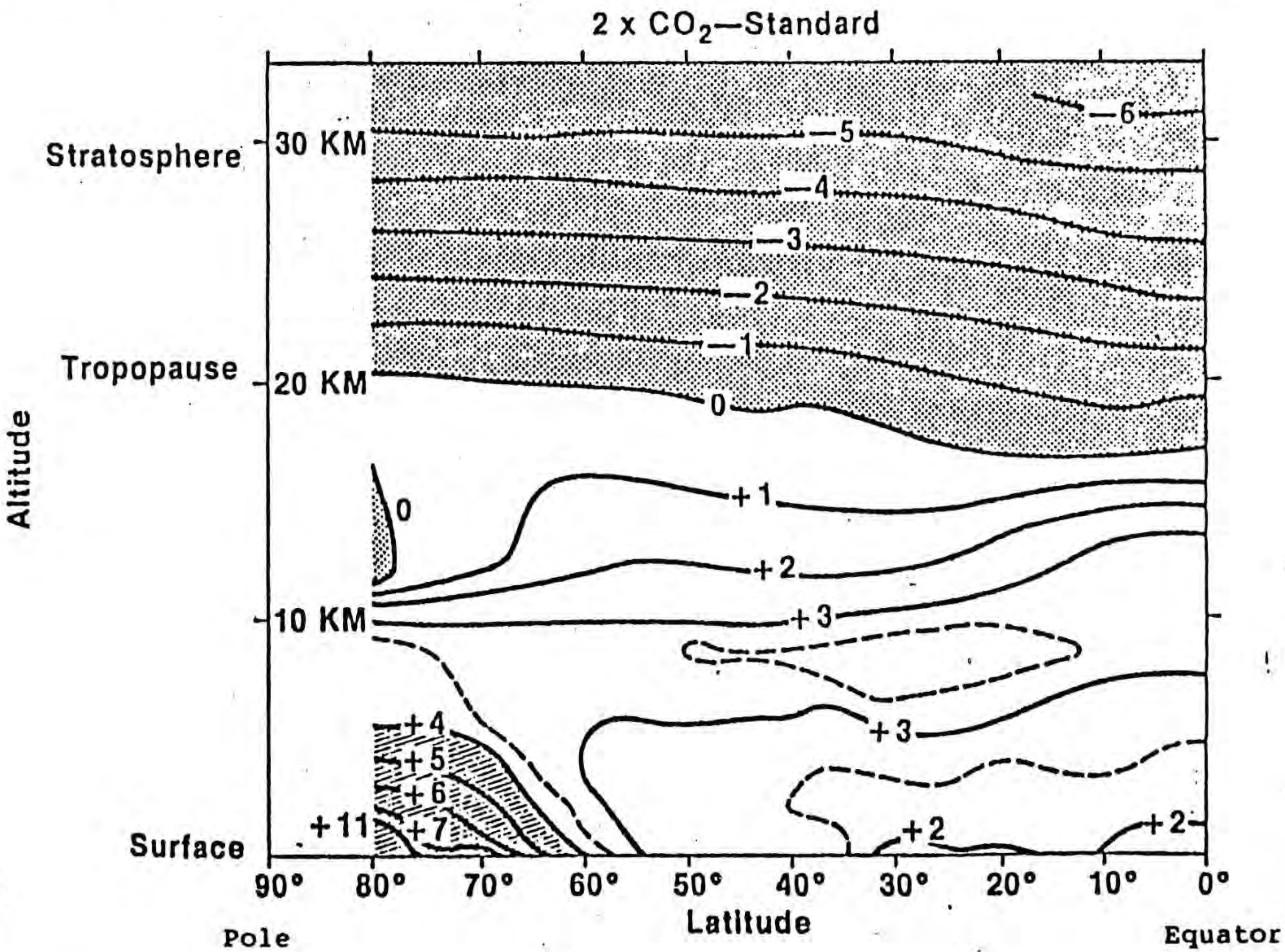


Figure 4

Temperature Change (^oC) Due to Doubling CO_2 Concentrations

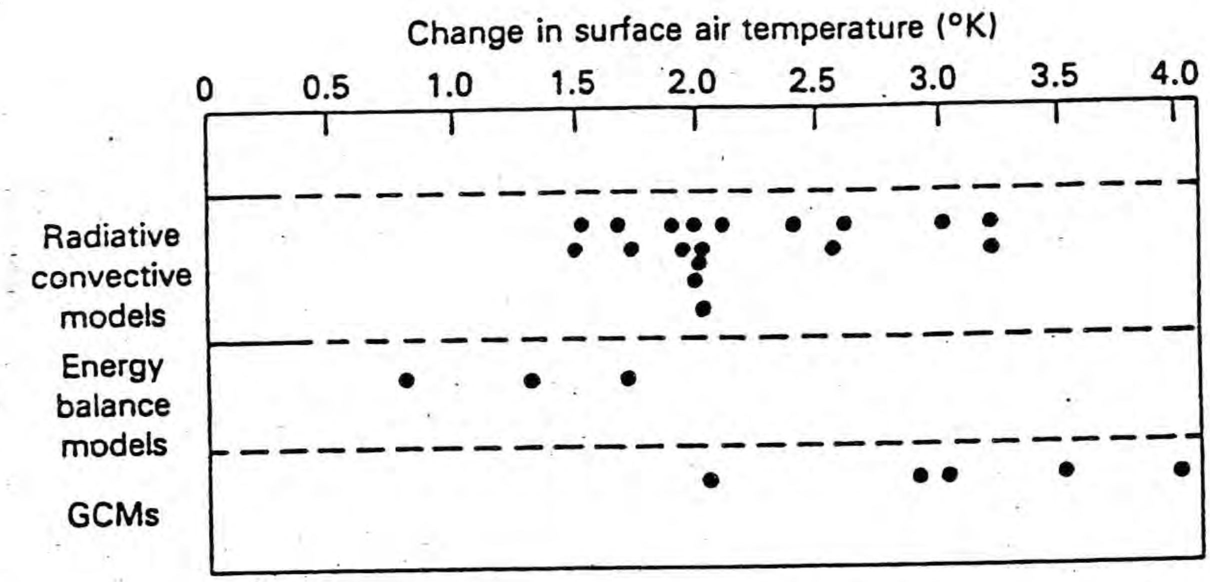
Basis: Computed by the U.S. National Oceanic and Atmospheric Administration using their general circulation model.



---- Decrease in Temperature

Ex. D-15

Figure 5



The change in globally averaged surface air temperature resulting from a doubling of atmospheric CO_2 as given by a variety of radiative-convective, energy balance, and global circulation (GCM) models. (From W. L. Gates, Oregon State University Technical Report no. 4.)

Ex. D-16

Figure 6

Estimates of the Change in Global Average Surface Temperature Due to Various Changes in CO_2 Concentration. Shading Shows Present Range of Natural Fluctuations.

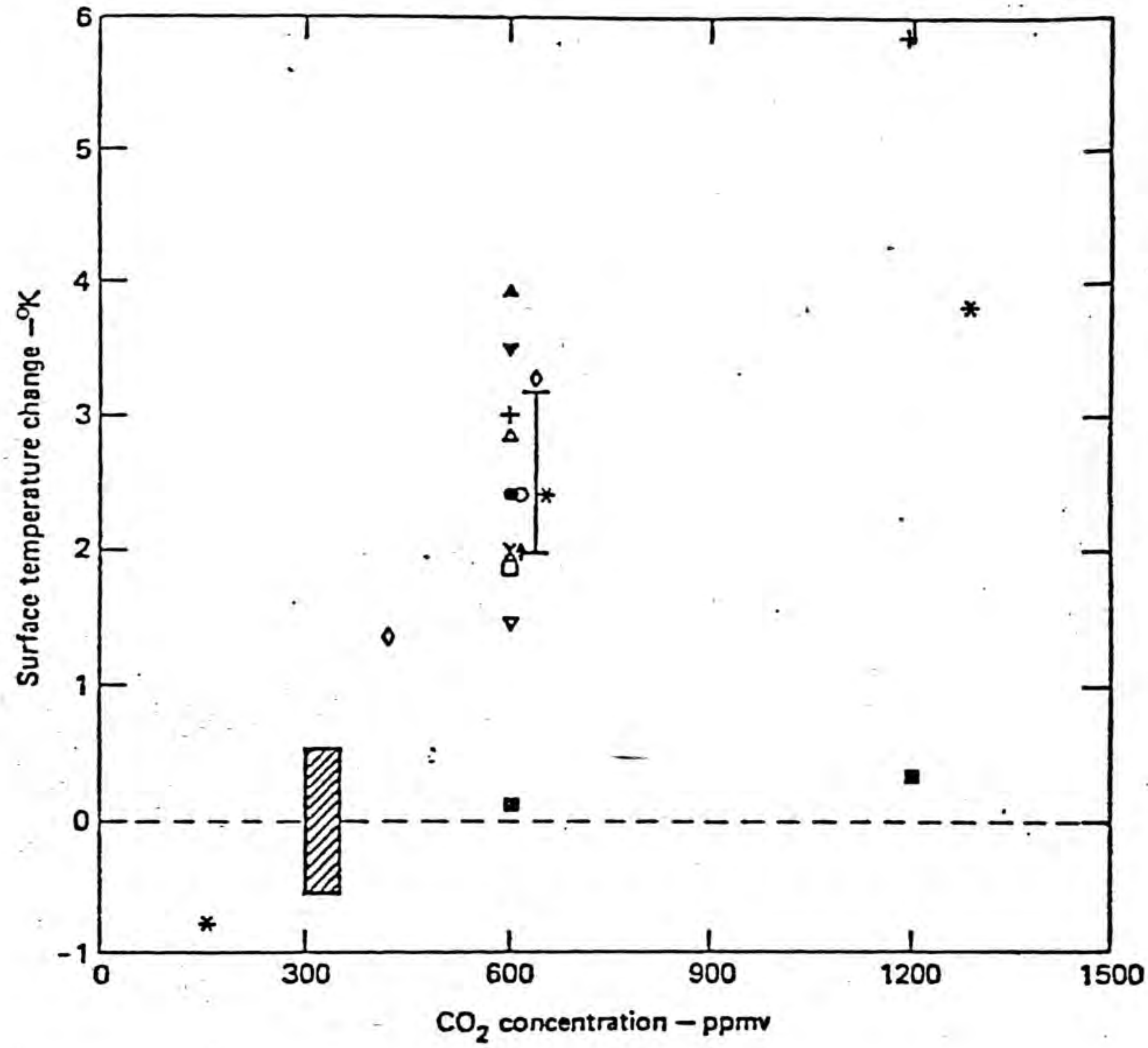
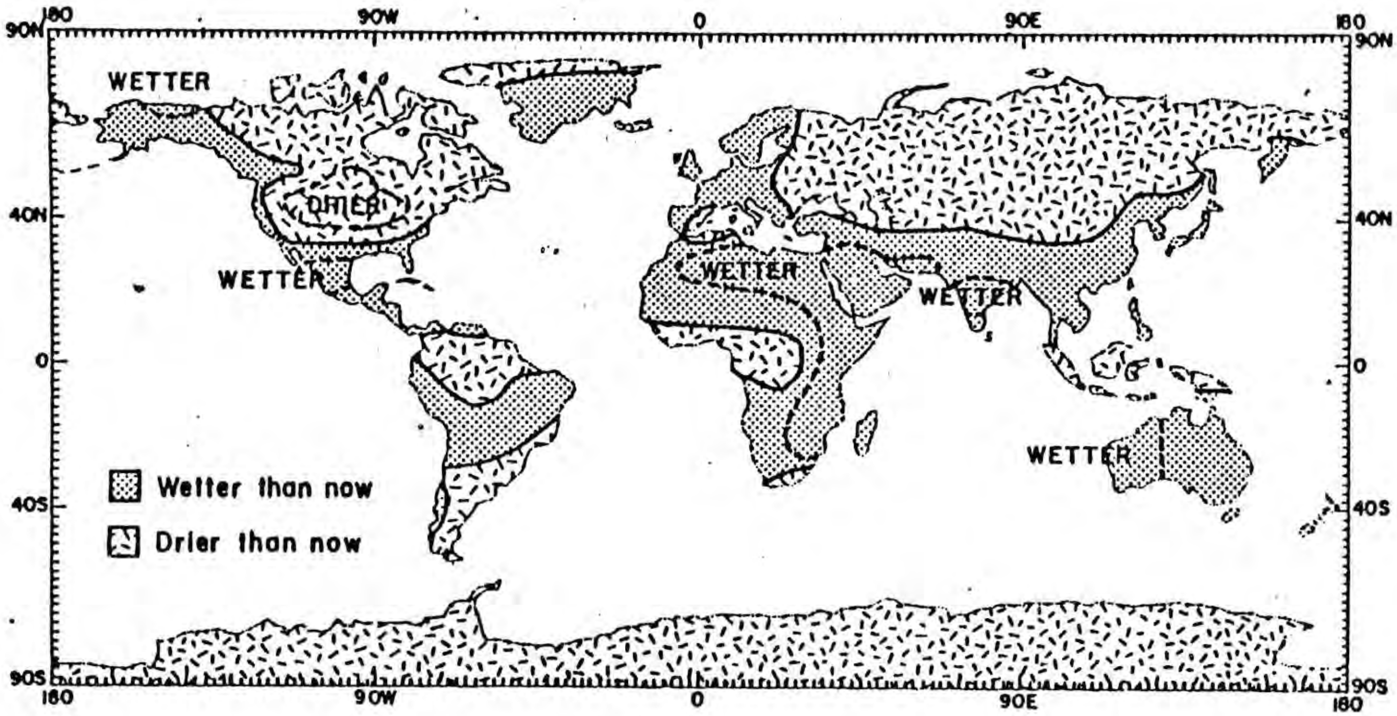


Figure 7



Example of a scenario of possible soil moisture patterns on a warmer Earth. It is based on paleoclimatic reconstructions of the Altithermal Period (4500 to 8000 years ago), comparisons of recent warm and cold years in the Northern Hemisphere, and a climate model experiment. (For a discussion of these sources of information see Appendix C.) Where two or more of these sources agree on the direction of the change we have indicated the area of agreement with a dashed line and a label.

their report titled, "Carbon Dioxide and Climate: A Scientific Assessment." This National Research Council study concluded that there are major uncertainties in these models in terms of the timing for a doubling of CO_2 and the resulting temperature increase. These uncertainties center around the thermal capacity of the oceans. The oceans have been assumed to consist of a relatively thin, well mixed surface layer averaging about 70 meters in depth in most of the general circulation models, and the transfer of heat into the deep ocean is essentially infinitely slow. The Charney panel felt, however, that the amount of heat carried by the deep ocean has been under estimated and the oceans will slow the temperature increase due to doubling of atmospheric CO_2. The Charney group estimated that the delay in heating resulting from the effect of the oceans could delay the expected temperature increase due to a doubling of CO_2 by a few decades. Accordingly, the time when the temperature increases discussed above are reached must be assumed to have occurred at an instantaneous equilibrium.

Along with a temperature increase, other climatological changes are expected to occur including an uneven global distribution of increased rainfall and increased evaporation. These disturbances in the existing global water distribution balance would have dramatic impact on soil moisture, and in turn, on agriculture. Recently, Manabe et al., using GCM's calculated that the zonal mean value of soil moisture in summer declines significantly in two separate zones of middle and high latitudes in response to an increase in the CO_2 concentration of air. This CO_2 induced summer dryness results not only from the earlier ending of the snowmelt season, but also from the earlier occurrence of the spring to summer reduction in rainfall rate. The former effect is particularly important in high latitudes, whereas the latter effect becomes important in middle latitudes. Other statistically significant changes include large increases in both soil moisture and runoff rates at high latitudes during most of the annual cycle with the exception of the summer season. The penetration of moisture rich, warm air into high latitudes is responsible for these increases.

The state-of-the-art in climate modeling allows only gross global zoning while some of the expected results from temperature increases of the magnitude indicated are quite dramatic. For example, areas that were deserts 4,000 to 8,000 years ago in the Altithermal period (when the global average temperature was some 2°C higher than present), may in due time return to deserts. Conversely, some areas which are deserts now were formerly agricultural regions. It is postulated that part of the Sahara Desert in Africa was quite wet 2,000 to 8,000 years ago. The American Midwest, on the other hand, was much drier, and it is projected that the Midwest would again become drier should there be a temperature increase of the magnitude postulated for a doubling of atmospheric CO_2 (see Figure 7).

In addition to the effects of climate on global agriculture, there are some potentially catastrophic events that must be considered. For example, if the Antarctic ice sheet which is anchored on land should melt, then this could cause a rise in sea level on the order of 5 meters. Such a rise would cause flooding on much of the U.S. East Coast, including the State of Florida and Washington, D.C. The melting rate of polar ice is being studied by a number of glacialogists. Estimates for the melting of the West Anarctica ice sheet range from hundreds of years to a thousand years. Etkins and Epstein observed a 45 mm raise in mean sea level. They account for the rise by assuming that the top 70 m of the oceans has warmed by 0.3°C from 1890 to 1940 (as has the atmosphere) causing a 24 mm rise in sea level due to thermal expansion. They attribute the rest of the sea level rise to melting of polar ice. However, melting 51 Tt (10^{12} metric tonnes) of ice would reduce ocean temperature by 0.2°C, and explain why the global mean surface temperature has not increased as predicted by CO_2 greenhouse theories.

In an American Association for the Advancement of Science (AAAS) and Department of Energy (DOE) sponsored workshop on the environmental and societal consequences of a possible CO_2 induced climate change, other factors such as the environmental effects of CO_2 concentration on weeds and pests were considered. The general consensus was that these unmanaged species would tend to thrive with increasing average global temperature. The managed biosphere, such as agriculture, would also tend to benefit from atmospheric CO_2 growth. This is a consequence of CO_2 benefiting agriculture, provided the other key nutrients, phosphorous and nitrogen, are present in the right proportions. Agricultural water needs can be met by new irrigation techniques that require less water. In addition, with higher CO_2 and higher temperature conditions, the amount of water needed by agricultural plants may be reduced. It is expected that bioscience contributions could point the way for dealing with climatological disruptions of the magnitude indicated above. As a result of the workshop, research in 11 areas was recommended:

1. CO_2 fertilization could have broad beneficial effects on agriculture. These effects need to be studied in detail and for a variety of plant, soil and climatic conditions.

2. There is a need for a fuller understanding of the dynamics of currents and water masses in the Arctic Ocean.

3. It is necessary to determine whether there was deglaciation of the West Antarctic ice sheet about 120,000 years ago and whether this caused a rise in global sea levels at that time. If this occurred, then the information could serve as an analog of future deglaciation.

4. It is necessary to develop and use scenarios which integrate (a) information about population, resources, energy consumption and fuel mixes; (b) buildup of atmospheric CO_2; (c) response of the climate system; (d) effects on various biological systems, especially agricultural, economic and social consequences, international and interregional conflicts; and (e) possible feedback among these forces.

5. CO_2 induced warming is predicted to be much greater at the polar regions. There could also be positive feedback mechanisms as deposits of peat, containing large reservoirs of organic carbon, are exposed to oxidation. Similarly, thawing might also release large quantities of carbon currently sequestered as methane hydrates. Quantitative estimates of these possible effects are needed.

6. Although all biological systems are likely to be affected, the most severe economic effects could be on agriculture. There is a need to examine methods for alleviating environmental stress on renewable resource production — food, fiber, animal, agriculture, tree crops, etc.

7. Information exists on the relationship of cultivated and non-cultivated biomes to climatic fluctuations. Similarly, there is considerable information on the response of various nations and economic sectors to climatic variations over the past few hundred years. This information, which is currently scattered and not uniformly presented or calibrated, is thus of limited usefulness.

8. Studies of climate effects are recommended for the semi-arid tropics because of the relatively large populations in these countries and because of special sensitivity to climate.

9. There are situations (soil erosion, salinization, or the collapse of irrigation systems) which are recommended for study as indicators of how societies respond, and how they might learn to cope and adapt more effectively to a shift in global climate.

10. Research is recommended on the flow of information on risk perception and decision making to and from both laymen and experts, the physiological aspects of understanding and perception, and the factors that influence decision making.

11. There is a need to be sure that "lifetime" exposure to elevated CO_2 poses no risks to the health of humans or animals. Health effects associated with changes in the climate sensitive parameters, or stress associated with climate related famine or migration could be significant, and deserve study.

In terms of the societal and institutional responses to an increase in CO_2, the AAAS-DOE workshop participants felt that society can adapt to the increase in CO_2 and that this problem is not as significant to mankind as a nuclear holocaust or world famine. Finally, in an analysis of the issues associated with economic and geopolitical consequences, it was felt that society can adapt to a CO_2 increase within economic constraints that will be existing at the time. Some adaptive measures that were tested would not consume more than a few percent of the gross national product estimated in the middle of the next century.

Major Research Programs Underway

The Department of Energy (DOE) which is acting as a focal point for the U.S. government in this area is planning to issue two reports to the scientific community and to policy makers. The first one, summarizing five years of study is due in 1984, and the second one in 1989. The current plan is to invest approximately 10 years of research and assessment prior to recommending policy decisions in this area which impact greatly on the energy needs and scenarios for the U.S. and the world. The strategic elements of the United States national total CO_2 program are summarized in Figure 8.

Much of the government sponsored effort to date has focused on delineating the research needed to enhance our understanding of the potential problems. Accordingly, a number of workshops and symposia were held to this end. The consensus of the key research needs is summarized in Figure 8 under the heading "Research Program Results." To date, most of the research effort has been concentrated on the first two research categories. It should be noted, however, that this research started in 1979 and there are few results to report. The most ambitious project being conducted at this time is called "Transient Tracer in the Ocean (TTO)." This research, jointly funded by the DOE and the National Science Foundation (NSF), is a 4M$ project to investigate ocean mixing processes in order to enhance the understanding of how surface water CO_2 is mixed into the deep ocean. Tracers normally found in the ocean, such as ^{14}C, ^{3}H, ^{3}He, ^{85}Kr and ^{39}Ar, are monitored in the North Atlantic Ocean from oceanographic vessels.

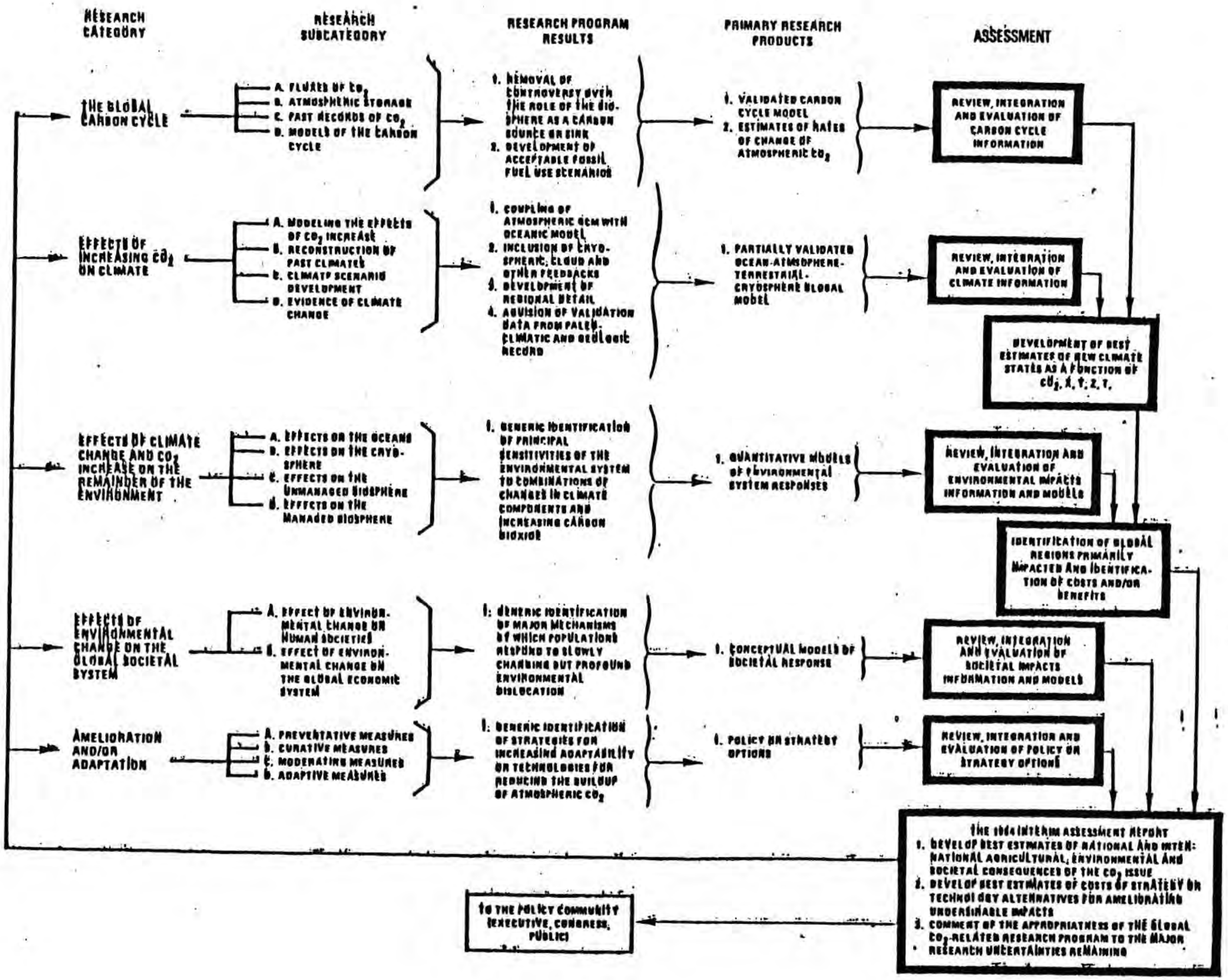
In addition to the mixing of surface waters into the bottom layers, carbon can be added to deep waters by the oxidation of organic matter and the dissolution of calcium carbonate. In order to separate these three processes and determine their relative significance, precise total carbon dioxide, alkalinity, and calcium concentration data are needed to construct and test mathematical models. Preliminary analysis of the limited data indicates that (1) lateral processes dominate the distribution of calcium and inorganic carbon in the deep oceans away from the polar regions, (2) the amount of calcium carbonate dissociated in the deep oceans is only a fraction of the previously estimated value, and (3) the excess CO_2 may have penetrated farther into the deep oceans than the currently available models predict.

Ultimately, CO_2 in the air should find its way into the deep ocean sediments. As currently understood, the deeper sediments have thus far been little affected by the fossil fuel era because of the slow mixing of the ocean. A group of scientists examined the contention that some shallow water sediments could now be dissolving and thus providing a sink for atmospheric CO_2, and concluded that the extent of dissolution is not great enough to have a large effect on the global carbon cycle.

It would be helpful if reliable estimates of the CO_2 concentration in the air could be obtained for the years prior to 1957, when the modern measurements

Figure 8

A NATIONAL PROGRAM ON CARBON DIOXIDE, ENVIRONMENT AND SOCIETY



Ex. D-23

began. Old Smithsonian Astrophysical Observatory plates of the solar spectrum taken in the early twentieth century might provide such an opportunity if they could be properly interpreted. A method for reducing the data has been developed and estimates of the CO_2 concentration should be available next year. As mentioned previously, determination of the CO_2 concentrations prior to the Industrial Revolution would help ascertain the validity of climate models, and thus the likely temperature due to a doubling of atmospheric CO_2.

Groups in Europe have used Antarctic and Greenland ice cores to independently estimate the CO_2 concentrations in the more distant past. While it is difficult to measure the CO_2 content of the dated ice cores, the results suggest that the atmospheric CO_2 concentration during the height of the last ice age (about 18,000 years ago) may have been about half its present value. This is consistent with recently published speculations derived from examination of the composition of ocean sediment cores.

There are currently approximately 40 carbon cycle and climate research projects in about 25 different institutions. Many of these projects are either supported jointly by the DOE and other agencies or exclusively by other agencies. The 1982 Federal budget request for CO_2 research was 23.9M$. The DOE, as the lead agency, would be allocated 14.0M$, NSF 6.4M$, NOAA 2.5M$, and the Department of Agriculture 1.0M$.

Future Energy Scenarios and Their Potential Impact on Atmospheric Carbon Dioxide

A number of future energy scenarios have been studied in relation to the CO_2 problem. These include such unlikely scenarios as stopping all fossil fuel combustion at the 1980 rate, looking at the delay in doubling time, and maintaining the pre-1973 fuel growth rate. Other studies have investigated the market penetration of non-fossil fuel technologies, such as nuclear, and its impact on CO_2. It should be noted, however, that fuel technology would need about 50 years to penetrate and achieve roughly half of the total market. Thus, even if solar or nuclear technologies were to be considered viable alternatives, they would not really displace fossil fuel energy for the next 40 to 50 years, and CO_2 growth would have to be estimated based on realistic market displacement of the fossil fuel technologies.

A draft report from Massachusetts Institute of Technology (MIT) and Oak Ridge (ORNL) authored by D. Rose and others considered the societal and technological inertia vis a vis decision making on the CO_2 issue. The CO_2 problem was considered as the major potential constraint on fossil fuel use. It was estimated in the study that the CO_2 problem may curtail fossil fuel use before physical depletion occurs. Considerable effort was devoted in the study to "option space," i.e., what are the potential energy alternatives, how long would it take to introduce them, and what type of material resources would be needed for effective market penetration. On reviewing the report we addressed only the technical questions relating to CO_2, and did not evaluate the plausibility of the scenarios relating to energy use in the future.

The study considered the implications of limiting atmospheric CO_2 at two different levels:

1. Rate of CO_2 addition to the atmosphere be limited to 450-500 ppm in 50 years.

2. The concentration ceiling for atmospheric CO_2 be in the range of 500-1000 ppm.

The rationale for choosing these limits is economic. If the rate of CO_2 increase is too rapid, then society may not be able to economically adapt to the resulting climate change. The second limit is based on a level where the harm due to CO_2 would greatly exceed the societal benefits that produced the CO_2. The second limit can be illustrated as an assumed threshold for inducing great irreversible harm to our planet, such as causing a large ocean level rise due to melting polar ice. In addition to improving the use of energy sources as a means of gaining time to understand the problem, it was concluded that vigorous development of non-fossil energy sources be initiated as soon as possible.

The study appears to be based on reasonable assumptions but has an inherent bias towards the accelerated development of non-fossil energy sources which, based on the present state-of-the-art, implies nuclear energy.

In his analysis, Rose introduced the concept of AIT (action initiation time), defined as the time when policies to modify or restrain fossil fuel use actually start to be effective. Based on this concept, Rose projects non-fossil growth rates of 6 to 9%/a over 40 to 50 years in order to limit atmospheric CO_2 to 500 to 700 ppm. These rates can be put in perspective by noting that such growth rates were achieved for natural gas introduction. However, nuclear or solar sources would have severe restrictions because such technologies are not as economically and politically attractive, technologically straightforward, and are encountering social and environmental opposition. In addition, Rose points out that the rate of growth of manufacturing facilities required to achieve a 6-9%/a growth rate in non-fossil fuel power generation is so large that it would be equivalent to increasing each year the U.S. power equipment manufacturing capability by an amount equivalent to the current capacity.

The study also indicated that other <u>energy-use-related</u> greenhouse gases (viz. carbon monoxide, methane, and oxides of nitrogen) may significantly contribute to a global warming. We believe the contribution of these gases to a global warming is highly speculative. Furthermore, N_2O, the only oxide of nitrogen that could contribute to a global warming is produced primarily by the microbial oxidation of ammonia from fertilizer use, and to a lesser extent from the combustion of fossil fuels. Additionally, N_2O is more reactive than CO_2 and is expected to have a relatively shorter atmospheric residence time. In a similar vein, methane is primarily emitted to the atmosphere via the anaerobic fermentation of organic material. The contribution of anthropogenic activities (mining, industrial processes, and combustion) are 1% to 10% of the total atmospheric methane sources. The atmospheric destruction of methane is more rapid than that of CO_2, and tends to yield CO, water vapor and formaldehyde. Also, methane is believed to contribute to tropospheric ozone formation by oxidizing to CO_2. The CO in the atmosphere can be traced to anthopogenic sources (50 to 60%) and to the atmospheric oxidation of methane (30%). The major CO sink is oxidation (70 to 90%) to CO_2. One can therefore consider CO and methane as precursors to CO_2. Accordingly, CO and methane ultimately contribute to climatological effects as part of atmospheric CO_2. The N_2O, on the other hand, may not be directly related to fossil fuel combustion. One should question whether the other "greenhouse" gases should be considered part of the CO_2 problem in view of the uncertainties regarding their connection to energy use. It is not clear, at this time, whether their effect would be additive to CO_2.

Forecast Based on Fossil Fuel Projected in Exxon's Long Range Energy Outlook

As part of the Exxon 21st Century Study, the rate of fossil fuel CO_2 emissions was estimated in late 1981. Specifically, the "High Case" volumetric data provided by the Corporate Planning Department was used to estimate the potential growth of atmospheric CO_2. The volumetric data was converted to an energy basis (Quads/a = 10^{15} Btu/year) using 5.55 MBtu/B for U.S., 5.64 MBtu/B for Canada and 5.85 MBtu/B for all other countries. In addition, a shale processing loss was added using a constant rate of 27.5% of the primary energy consumption from shale. This was based on the assumption that above ground retorting of relatively high quality oil shale (>30 gallons/ton) would be recovered with a thermal efficiency of 80%, and in-situ recovery of relatively poor oil shale (>15 gallons/ton) would be accomplished with a thermal efficiency of 65%. These efficiencies were averaged over the U.S. resource base to arrive at 72.5%. Table 1 summarizes the primary energy consumption of fossil fuels.

The total carbon dioxide that can be emitted from primary fossil fuels was estimated using the following factors:

Oil = 170 lb CO_2/MBtu = 21.0 MtC*/Quad.

Gas = 115 lb CO_2/MBtu = 14.2 MtC/Quad.

Coal = 207 lb CO_2/MBtu = 25.6 MtC/Quad.

In addition, the quantity of carbon dioxide that could be emitted from the decomposition of carbonate minerals in processing U.S. oil shale was estimated by averaging this potentially large CO_2 source over the Green River formation resource base. It should be noted that poorer shale resources tend to

* MtC = million metric tons of carbon.

PRIMARY ENERGY CONSUMPTION OF FOSSIL FUELS
21st CENTURY STUDY--HIGH CASE

Quads/a

Year	1979	1990	2000	2015	2030	2050
Oil						
U.S.	37.09	33.32	32.01	35.35	36.35	36.80
Canada	4.06	4.30	4.71	5.62	6.09	5.97
Others	96.62	111.93	128.16	139.63	148.57	132.75
Total	137.77	149.55	164.88	180.60	191.01	175.52
Gas						
U.S.	20.95	17.83	17.24	15.98	16.87	17.42
Canada	1.83	2.51	2.88	3.48	4.38	4.73
Others	30.88	55.54	74.95	86.24	99.65	108.68
Total	53.66	75.88	95.07	105.70	120.90	130.83
Coal						
U.S.	14.69	20.14	28.66	37.19	43.17	55.10
Canada	0.80	1.37	1.98	2.72	3.62	5.35
Others	60.17	81.44	103.90	125.55	175.55	261.14
Total	75.66	102.95	134.54	165.41	222.54	321.59
Fossil Fuels						
World Total	267.09	328.38	394.49	451.71	534.45	627.94
Rate %/a		1.90	1.85	0.91	1.13	0.81

Ex. D-27

emit much more CO_2 from carbonate minerals than the more desirable high quality resources for the same quantity of shale oil produced. It was further assumed that 65% of the carbonate minerals decompose during processing. This very conservative assumption is based on the average of 100% decomposition that may occur in "hot spots" during in-situ recovery and 30% decomposition that is generally observed in above ground retorting. Table 2 summarizes the total CO_2 produced in GtC/a. Please note that CO_2 emissions resulting from CO_2 mixed with natural gas in producing wells can be substantial, but due to the unavailability of quantitative data this factor was assumed to contribute about 5% additional CO_2 currently rising to 15% in the year 2050. This trend of CO_2 contamination of natural gas is consistent with recent Exxon experience.

The contributions of shale oil to primary fossil fuel energy and primary fossil fuel carbon are summarized in Table 3. This table shows that the fraction of shale oil CO_2 emissions to total CO_2 is greater than the corresponding contribution of shale oil energy to total energy. Table 3 also indicates the breakdown between CO_2 generated in producing and consuming shale oil, and that due to carbonate mineral decomposition.

Table 4 presents the estimated total quantities of CO_2 emitted to the environment as GtC, the growth of CO_2 in the atmosphere in ppm (v), and average global temperature increase in $^{\circ}C$ over 1979 as the base year. In order to estimate the buildup of atmospheric CO_2, it was assumed that the average atmospheric CO_2 concentration was 337 ppm in 1979. The fraction of CO_2 accumulated in the atmosphere was assumed to be 0.535 of the total fossil fuel CO_2. This number is derived from the observed historic ratio of total atmospheric CO_2 to total fossil fuel CO_2. Inherent in this number is the assumption that biomass and cement production did not contribute to atmospheric CO_2. It should be noted, however, that this method of calculation would tend to predict total anthropogenic CO_2 as long as the ratio of biomass and cement manufacture to fossil fuel consumption remains constant. The average temperature increase since 1979 was estimated, assuming that a doubling of CO_2 would cause an average global temperature increase of $3.0^{\circ} \pm 1.5^{\circ}C$. It was also assumed that fossil fuel carbon would grow at a rate of 0.8%/a between 2050 and 2080, which is a reasonable decrease from the 0.97%/a rate projected between 2030 and 2050. The following section analyzes the implications of the temperature rise due to CO_2 doubling with respect to initial detection of a greenhouse effect.

One variation of the High Case scenario was considered. It was assumed that adequate quantities of oil and gas would be discovered to exactly match those estimated to be produced from synthetic fuels in the High Case scenario, and thus balance the primary energy needs of the 21st Century Study. The net quantity of carbon that would be saved is summarized in Table 5. The implications of the synfuel losses are compared with the High Case in Figure 3. The overall impact is relatively minor.

TABLE 2

PRIMARY CARBON DIOXIDE (AS CARBON) FORMATION FROM FOSSIL FUELS
21st CENTURY STUDY--HIGH CASE

GtC/a

Year	1979	1990	2000	2015	2030	2050
Oil	2.90	3.15	3.47	3.79	4.01	3.69
Inorganic Carbon	-	0.01	0.05	0.19	0.27	0.40
Total Oil	2.90	3.16	3.52	3.98	4.28	4.09
Gas	0.76	1.08	1.35	1.50	1.72	1.86
CO_2 in Gas	0.04	0.11	0.15	0.18	0.22	0.28
Total Gas	0.80	1.19	1.50	1.68	1.94	2.14
Total Coal	1.93	2.64	3.45	4.24	5.70	8.24
World Total	5.63	7.00	8.47	9.90	11.92	14.47
Rate %/a	2.00	1.92	1.05	1.25	0.97	0.80

TABLE 3

OIL SHALE LIQUID FUELS
PRIMARY ENERGY CONSUMPTION AND
CARBON DIOXIDE (AS CARBON) PRODUCTION
21st CENTURY STUDY--HIGH CASE

Year	1979	1990	2000	2015	2030	2050
U.S. Shale, Quads/a	--	1.01	3.65	14.38	20.66	30.79
Other Shale	--	0.21	1.49	2.56	5.55	11.10
Total	--	1.21	5.14	16.94	26.21	41.89
% Primary Shale Energy/Primary Fossil Fuels Energy	--	0.35	1.30	3.75	4.90	6.67
Shale Carbon, GtC/A	--	0.03	0.11	0.36	0.55	0.88
Carbonate Carbon	--	0.01	0.05	0.19	0.27	0.40
Total	--	0.04	0.16	0.55	0.82	1.28
% Primary Shale Carbon/Primary Fossil Fuel Carbon	--	0.55	1.89	5.55	6.87	8.85

Ex. D-30

TABLE 4

ESTIMATED ATMOSPHERIC CO_2 CONCENTRATION AND AVERAGE TEMPERATURE INCREASE
21st CENTURY STUDY--HIGH CASE

Year	Emitted, GtC		Stored in Atmosphere, GtC		Atmospheric Concentration, ppm		Average Temperature Increase, °C
	Incremental	Cummulative	Incremental	Cummulative	Incremental	Cummulative	
1979	--	--	--	715	--	337	0
1990	69.3	69.3	37.1	752	17.5	355	0.22
2000	77.2	146.5	41.3	793	19.5	374	0.45
2015	137.5	284.0	73.6	867	34.7	409	0.84
2030	163.3	447.3	87.4	954	41.2	450	1.25
2050	263.5	710.8	141.0	1095	66.5	516	1.84
2080	490.6	1201.4	262.5	1358	123.7	640	2.78
2090	191.3	1392.7	102.3	1160	48.2	688	3.09

Ex. D-31

TABLE 5

ESTIMATED INCREMENTAL CO_2 CONTRIBUTION FROM SYNTHETIC FUELS TO ATMOSPHERIC CO_2 CONCENTRATION AND AVERAGE GLOBAL TEMPERATURE INCREASE

GtC/a

Year	1990	2000	2015	2030	2050	2080
Shale Loss	0.004	0.025	0.069	0.114	0.181	
Carbonate Decomposition	0.013	0.047	0.186	0.267	0.398	
Total Shale	0.017	0.072	0.255	0.381	0.579	
Coal Loss	0.018	0.067	0.136	0.276	0.535	
Total Synfuels Loss	0.035	0.139	0.391	0.657	1.114	
Rate %/a		14.8	7.1	3.5	2.7	2.0
Incremental CO_2, GtC	-	0.80	3.73	7.73	17.38	45.79
Cummulative CO_2, GtC	-	0.80	4.53	12.26	29.64	75.43
Incremental Atmospheric CO_2, ppm	-	0.2	0.9	1.9	4.4	11.5
Cummulative Atmospheric CO_2, ppm	-	0.2	1.1	3.1	7.5	19
Net Atmospheric CO_2, ppm	355	374	407	446	506	616
Average Temperature Increase, °C	0.22	0.45	0.82	1.21	1.76	2.61

Ex. D-32

Detection of a CO_2 Greenhouse Effect

It is anticipated by most scientists that a general consensus regarding the likelihood and implications of a CO_2 induced greenhouse effect will not be reached until such time as a significant temperature increase can be detected above the natural random temperature fluctuations in average global climate. These fluctuations are assumed to be $\pm 0.5^{\circ}C$. The earliest that such discreet signals will be able to be measured is one of the major uncertainties of the CO_2 issue.

A number of climatologists claim that they are currently measuring a temperature signal (above climate noise) due to a CO_2 induced greenhouse effect, while the majority do not expect such a signal to be detectable before the year 2000. In order to quantify the implications of detecting a greenhouse effect now, as opposed to the year 2000, estimates were made on temperature projections as a function of the CO_2 concentration that existed prior to the Industrial Revolution. Available data on CO_2 concentration prior to the Industrial Revolution tend to fall into two groups: 260 to 270 ppm or 290 to 300 ppm. In Table 6, possible temperature increases were estimated as a function of initial CO_2 concentrations of 265 and 295 ppm. Temperatures were projected for three cases, viz., (1) a temperature increase of $3^{\circ}C$ occurs if current CO_2 concentration doubles, (2) the greenhouse effect is detectable now (1979), and (3) the greenhouse affect is detected in the year 2000.

One can see in Table 6 that if a doubling of atmospheric CO_2 will cause a $3^{\circ}C$ rise in temperature, then we should have seen a temperature increase above climate noise if initial CO_2 concentration was 265 ppm, or be on the threshold of detecting such an effect now, if the initial concentration was 295 ppm. If we assume that we are on the threshold of detecting a greenhouse effect, then the average temperature due to a doubling of CO_2 will be $1.9^{\circ}C$ for an initial CO_2 concentration of 265, or $3.1^{\circ}C$ for an initial concentration of 295 ppm. Finally, if the greenhouse effect is detected in the year 2000, then the doubling temperature for initial CO_2 concentrations of 265 and 295 ppm will be 1.3° and $1.7^{\circ}C$, respectively. Based on these estimates, one concludes that a doubling of current concentrations of CO_2 will probably not cause an average global temperature rise much in excess of $3^{\circ}C$, or the effect should be detectable at the present time. Alternatively, if the greenhouse effect is not detected until 2000, then the temperature due to a CO_2 doubling will probably be under $2^{\circ}C$. Using the Exxon 21st Century Study as a basis for fossil fuel growth patterns, the average global temperature increases due to CO_2 would range between 0.8 and $1.6^{\circ}C$ by 2030. A doubling of atmospheric CO_2 would be extropolated from the fossil fuel consumption rates of the 21st Century Study to occur at about the year 2090 with the temperature increase ranging between 1.3° and $3.1^{\circ}C$. The projected range presented above is considerably lower than the generally accepted range of 1.5° to $4.5^{\circ}C$. Figure 9 illustrates

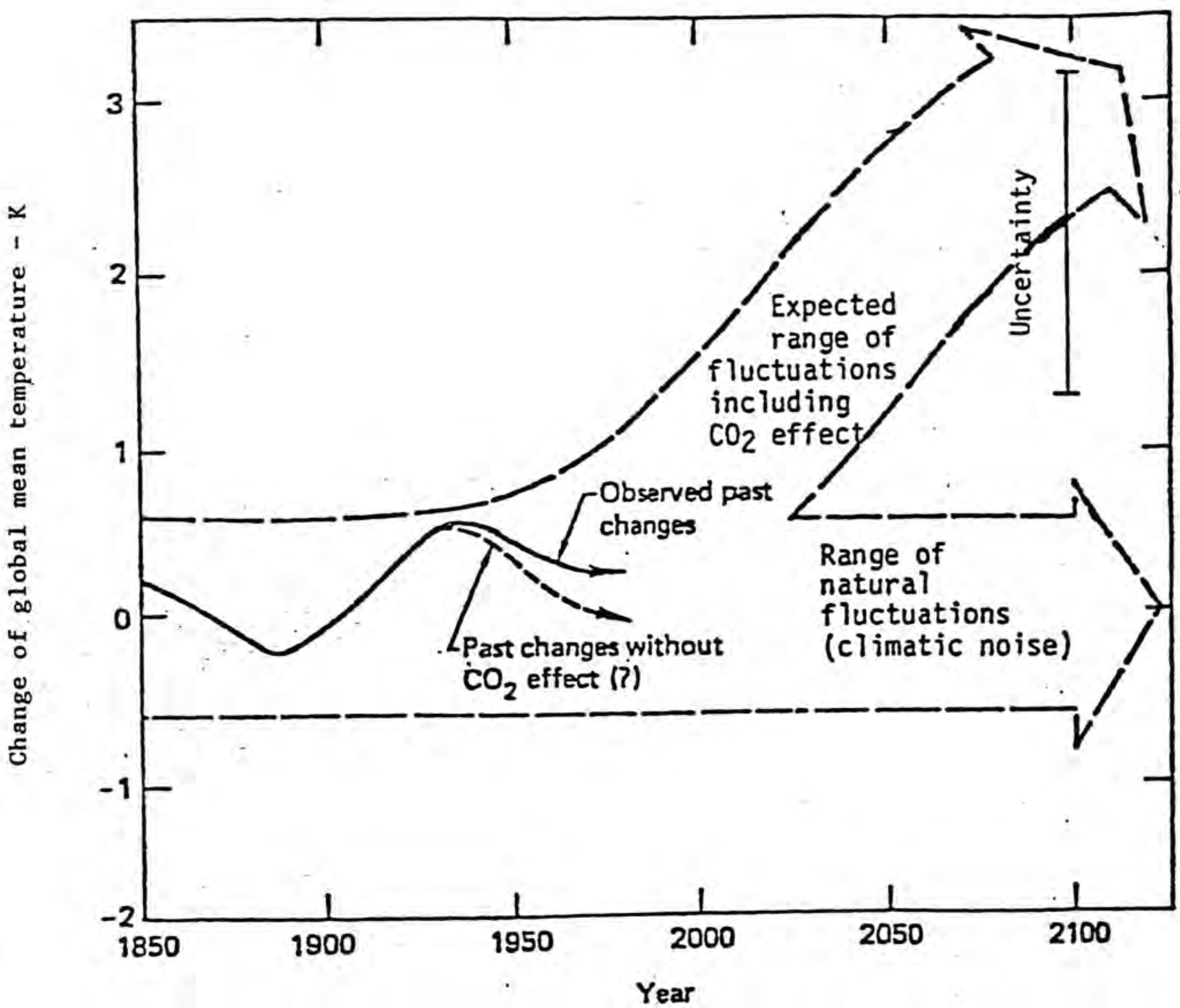
TABLE 6

EFFECT OF PRE-INDUSTRIAL ATMOSPHERIC CO_2 CONCENTRATION ON GLOBAL AVERAGE TEMPERATURE INCREASE

Atmospheric CO2 Concentration, ppm	Time (Instantaneous Equilibrium)	Temperature, °C Doubling ~2090 265	Temperature, °C Doubling ~2090 295	Temperature, °C Detected 1979 265	Temperature, °C Detected 1979 295	Temperature, °C Detected 2000 265	Temperature, °C Detected 2000 295
1,000	~2140	4.3	4.4	2.8	4.6	1.9	2.5
800	~2110	3.6	3.6	2.3	3.7	1.4	2.1
674 (Doubling)	~2090	3.0	3.0	1.9	3.1	1.3	1.7
451	2030	1.7	1.5	1.1	1.6	0.8	0.9
375	2000	1.1	0.9	0.7	0.9	0.5	0.5
337 (Current)	1979	0.8	0.5	0.5	0.5	0.3	0.3
295	~1850	0.3	0	0.2	0	0.2	0
265	~1850	0	-	0	-	0	-

Figure 9

Range of Global Mean Temperature From 1850 to the Present with the Projected Instantaneous Climatic Response to Increasing CO_2 Concentrations.



Ex. D-35

the behavior of the mean global temperature from 1850 to the present, contained within an envelop scaled to include the random temperature fluctuations, and projected into the future to include the 1.3^{o} to $3.1^{o}C$ range of uncertainty noted above for the CO_2 effect.

Depending on the actual global energy demand and supply, it is possible that some of the concerns about CO_2 growth due to fossil fuel combustion may be reduced if fossil fuel use is decreased due to high price, scarcity, and unavailability.

The above discussion assumes that an instantaneous climatic response results from an increase in atmospheric CO_2 concentration. In actuality, the temperature effect would likely lag the CO_2 change by about 20 years because the oceans would tend to damp out temperature changes.

Given the long term nature of the potential problem and the uncertainties involved, it would appear that there is time for further study and monitoring before specific actions need be taken. At the present time, that action would likely be curtailment of fossil fuel consumption which would undoubtedly seriously impact the world's economies and societies. Key points needing better definition include the impact of fossil fuel combusion and the role of the oceans in the carbon cycle and the interactive effect of carbon dioxide and other trace atmospheric gases on climate.

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Exhibit E

GENERAL 7A
MEMORANDUM

TO D. E. Smiley

FROM HENRY SHAW

DATE December 5, 1980

Attached is a copy of my comments to the NCAQ. Note that my comments are underlined and the original text that was deleted is indicated by hyphens across the words.

Henry

Henry Shaw

HS/lw

Attachment

cc: H. C. Hayworth
H. N. Weinberg

Ex. E-1

EXXON RESEARCH AND ENGINEERING COMPANY
CORPORATE RESEARCH
TECHNOLOGY FEASIBILITY CENTER
P.O. BOX 45, LINDEN, N.J. 07036

H. C. HAYWORTH, Manager
Contract Research Division

December 5, 1980

Ms. Alexis Hoskins/Mr. Joe Duckett
Schwartz & Connolly, Incorporated
1747 Pennsylvania Avenue, N.W.
Washington, D.C. 20006

Dear Messrs. Hoskins and Duckett:

Attached is a marked up copy of the draft statement of the workshop findings. My comments are based on my understanding of the potential CO_2 problem and do not reflect the Friday morning discussion which I unfortunately missed. I feel comfortable with the spirit of the recommendations, although I would like to see the wording of the policy recommendations made more specific.

Please let me know if I can be of further help.

Very truly yours,

Henry Shaw

Henry Shaw

HS/lw

Attachment

Ex. E-2

NATIONAL COMMISSION ON AIR QUALITY CO_2 WORKSHOP
DRAFT STATEMENT OF FINDINGS AND RECOMMENDATIONS

Introduction

Over the past twenty years, an increase in the global atmospheric concentration of carbon dioxide (CO_2) has been observed. This increase has been attributed primarily to the combustion of fossil fuels, and to a lesser extent, to land use practices (such as deforestation) which alter the net storage of carbon in vegetation and soils. Although the contributions to atmospheric CO_2 from these activities are not known precisely, it has been estimated that the amount of carbon stored in the fossil fuels/shale reservoir and in forests (including their soils) represents approximately seven and three ~~two~~ times, respectively, the amount held in the atmosphere.

Climate models indicate that if ~~If the increase in~~ atmospheric CO_2 levels continue ~~continues~~ to increase ~~take place~~ at existing or accelerated rates, a globally-averaged warming of the lower atmosphere, possibly leading to changes in world climate (such as changes in the distribution of precipitation) may ~~almost surely will~~ occur. For example, an *ad hoc* group of the National Academy of Sciences' Climate Research Board recently evaluated the results from a number of climatological models, and indicated that based on the current state-of-the-art (which is quite rudimentry), ~~predicted that~~ a global increase of $3^oC \pm 1.5^oC$ in the annual average temperature is the best estimate that can be made for ~~will probably result from~~ a doubling of the atmospheric concentration of CO_2. However, such changes in temperature ~~climate~~ are expected to occur with uneven geographic distribution, with greater warming occurring at the higher latitudes.

Ex. E-3

Among the postulated possible ~~potential-direct~~ results of ~~such~~ alterations in world climate due to a global temperature increase are changes in agriculture; in the stability, distribution, and productivity of natural ecosystems; and eventually; the sea level (due to the collapse of a portion of the West Antartic ~~polar~~ ice sheet). Although changes in climate have occurred naturally since the earth was formed, changes resulting from man-induced increases in the CO_2 content of the atmosphere are of special concern because they can occur within a century, ~~over-decades,~~ rather than over millenia, and because the increases are expected to persist for hundreds of years.

At present, there are substantial scientific uncertainties concerning anthropogenic sources of ~~the-relationship-between-human-activities,~~ atmospheric ~~levels-of~~ carbon dioxide, and their impact on climate and the global environment. In the U.S., a comprehensive research plan to address the ~~these~~ uncertainties associated with the consequences of a build-up of atmospheric CO_2 is being developed under the auspices of the National Climate Program. In addition, a number of international initiatives concerning CO_2 have recently been undertaken, such as the development of a coordinated plan of action for international research. Despite the ~~these~~ large scientific uncertainties, however, some members of the scientific community and others have advocated that actions be taken to prevent or mitigate CO_2-induced climate change. Notably, a panel of scientists attending the International Workshop on Energy/Climate Interactions (held in March, 1980 in Munster, F.R.G.) recommended that in light of the potential magnitude and irreversibility of CO_2-induced climate change,

Ex. E-4

the global consumption of fossil fuels should be stabilized at the 1980 levels. It should be noted, however, that Congressional testimony by key scientific experts in the relevant disciplines dealing with the CO_2 question recommended that our energy options not be narrowed at this time[1].

The primary purpose of this NCAQ workshop [this will have been introduced in an earlier section of the full report] was to bring together scientists and policy-makers to assess whether the potential consequences of anthropogenic increases in atmospheric CO_2 levels are substantial ~~significant~~ enough to warrant development of public policy responses. Although all workshop participants may not necessarily agree with each of the findings and recommendations as expressed below, the following statemand represents a general consensus among the participants.

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(1) Committee on Governmental Affairs, United States Senate, "Carbon Dioxide Accumulation in the Atmosphere, Synthetic Fuels and Ener Policy-A Symposium" July 30, 1979.

Ex. E-5

Findings

1. While CO_2-induced changes in global climate may have certain beneficial effects, it is believed that the net consequences of these changes will be adverse to the stability of human and natural communities.

2. In the next few decades, there are no ~~not~~ likely ~~to-be~~ technological "fixes" (e.g., emission control devices or techniques) that will provide practical means of controlling CO_2 emissions resulting from combustion.

3. In policy actions to control the increased CO_2 loading of the atmosphere are delayed until climate changes resulting from such an increase are discernible, then it is likely that they will occur too late to be effective.

4. In light of finding #3, ~~and-of-the-difficulty-of,-and-long-time required-for,-resolving-the-scientific-uncertainties-surrounding-the CO2-issue,~~ it is likely that policy actions to control the ~~long-term~~ growth of atmospheric CO_2 levels will need to be taken with imperfect knowledge of the probability and consequences of CO_2-induced climate change.

5. There appear to be few, if any, precedents for the U.S. political system to address a potential problem whose potential impact ~~nature~~ is as far in the future ~~long-term~~ as that of the CO_2 issue. That is, the potential societal cost ~~costs~~ of a CO_2-induced climate change

Ex. E-6

will not be borne for many decades, while the costs of avoiding such change would primarily be incurred in the near term. Therefore, it will be very difficult, but important ~~yet-it-is-essential,~~ to place the CO_2 issue on the nation's public policy agenda.

6. At present, the federal government together with the private sector are considering policy options for revitalizing U.S. industry. This revitalization effort will establish energy consumption and fuel use patterns that will likely have a significant impact on future man-induced emissions of CO_2. It is therefore timely to consider ways of reducing CO_2 emissions now, while industrial revitalization policies are being formulated.

7. Policies to control atmospheric levels of CO_2 should be international in scope. Unilateral action by the U.S. can be an important first step in initiating international action but cannot, by itself, control atmospheric CO_2 levels. Thus, it is important to sharply accelerate international dialogue concerning the CO_2 issue, through both existing and new mechanisms devised for this end.

Recommendations

A conclusion drawn from the above-listed findings is that consequences associated with increased atmospheric concentrations of CO_2 dictates the need for (a) conducting additional research and (b) taking certain policy-related actions.

a. Research Recommendations

1. This point seems to belong under policy recommendations. Research on the CO_2 issue should be assigned a high priority in responsible federal agencies. For example, the Congress could amend the National Climate Program Act (P.L. 95-367) by recognizing the role of present federal CO_2 research programs in the National Climate Program and by confirming the Department of Energy as the lead agency for the CO_2 research efforts.

2. Within the domestic and international CO_2 research programs, high priority should be assigned to research which is essential for answering key policy-related questions. Examples of ~~For example,~~ specific research topics ~~important to resolving policy-related questions~~ include:

- improved understanding of the carbon cycle;
- improvements in predictive models to better estimate the likelihood and magnitude of CO_2-induced climate change;
- improvements in the ability to detect climate change;
- projections of climate impacts on a regional basis, and
- assessments of the potential social, environmental, economic and political consequences of CO_2-induced climate change.

Ex. E-8

3. The U.S. should vigorously support international programs and activities that will advance our understanding of the CO_2 issue, and which will foster development of an international scientific consensus on the issue. For example, the U.S. could propose a Resolution to the United Nations General Assembly endorsing the World Climate Program.

4. The CO_2 issue is going to be ~~rapidly~~ shifting from a purely scientific question to one which also involves a variety of public policy issues in the next decade. The contributions of social and political scientists are essential to the identification and analysis of alternative policy responses and should be involved in the CO_2 research program. For example, groups such as the International Council of Scientific Unions (ICSU) should be encouraged to broaden their membership to include representation by the social and political science disciplines.

b. Policy-Related Recommendations

1. The U.S. should consider an increases ~~increase~~ in the rate of CO_2 emissions as probably a~~n~~ undesirable ~~condition~~ and should explicitly seek ~~to-control-the-long-term-growth-of-CO2-emissions in~~ to develop discussions on ~~developing~~ national and international policies (e.g., concerning subsidies, regulation, research, import/export and other programs) designed to affect energy

supply and consumption. During deliberations concerning these policies, the differences in CO_2 emissions per unit of energy output of the different fossil fuels should be weighed ~~heavily~~.* However, the market penetration of new technologies that would produce more net CO_2 per unit of useful energy, such as synfuels, is sufficiently slow to cause relatively minor concern about accelerating the CO_2 build-up over the century.

2. The U.S. should shift national policy to emphasize conservation and energy efficiency. Such an emphasis by the world's largest consumer of fossil fuels ~~would help control the rate of increase in atmospheric CO_2 levels, and~~ would serve as a means of exercising international leadership in reducing the risks and potential consequences of CO_2-induced climate change.

3. The U.S. should provide greater resources for developing efficient alternatives to fossil fuels, fully recognizing that all external costs must be carefully weighed in evaluating the desirability of any energy alternative. The group does not explicitly or implicitly endorse any particular non-fossil form of energy.

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* (For example, it has been estimated that the relative amounts of CO_2 released in the production of a unit of energy from various fossil fuels are: natural gas -- 1.0, oil -- 1.5, coal -- 1.8, shale oil -- 2.1, coal-derived gas -- 3.0, and coal-derived oil -- 2.8)

Ex. E-10

4. In light of finding #6, national policies and private activities regarding industrial revitalization should, if at all possible, be designed so as to assist in controlling the ~~long-term~~ growth of CO_2 emissions.

5. ~~Since-the-role-of-forests-and-their-soil-in-the-global-CO_2-budget and-in-affecting-the-CO_2-content-of-the-atmosphere-is-substantial,~~ U.S. policies designed to control the ~~long-term~~ growth of atmospheric CO_2 ~~releases~~ should recognize the management of forests as a stabilizing factor of the world carbon cycle. Specifically, the U.S. should establish domestic and foreign policies which:

   - discourage deforestation and other land use practices which contribute to increased atmospheric CO_2 levels, and
   - encourage activities, such as reforestation, which will help mitigate the CO_2 problem.

6. As a high priority, the U.S. should undertake to enter into international arrangements to foster cooperative research on the CO_2 issue and should undertake, in cooperation with other countries, international measures aimed at long-term control of CO_2 release. ~~releases.~~ [Please provide examples of the types of international measures which could be undertaken.] Encourage nuclear development by selling nuclear fuel and reprocessing it.

Ex. E-11

7. Currently, discussions are being held within the international scientific community concerning the formation of an international carbon dioxide assessment board to provide authoritative and unbiased evaluations of the nature, magnitude, and implications of growing atmospheric levels of CO_2. The U.S. should support the formation of such a board. This board should be established under non-governmental auspices, (e.g., through the International Council of Scientific Unions--ICSU), and with the cooperation and support of interested intergovernmental organizations, (e.g., the World Meteorological Organization--WMO, the United Nations Environment Programme--UNEP, and the Organization for Economic Cooperation and Development--OECD, etc.).

8. The U.S. should ensure that the CO_2 issue is adequately considered in the international forums, such as the 1981 U.N. Conference on New and Renewable Sources of Energy.

Ex. E-13

Exhibit F

CO_2 GREENHOUSE AND CLIMATE ISSUES

HENRY SHAW

PRESENTED AT

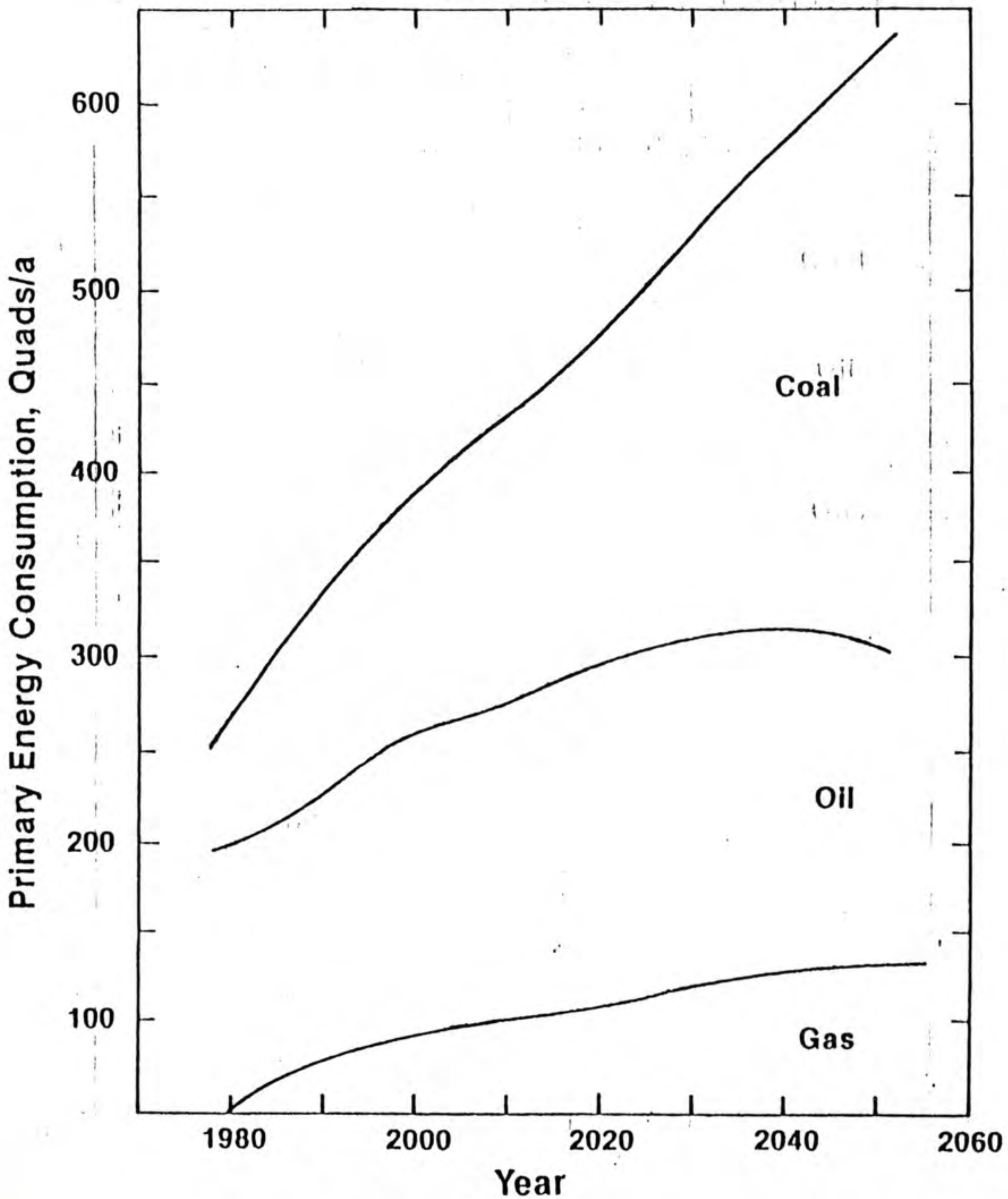
EUSA/ER&E ENVIRONMENTAL CONFERENCE

FLORHAM PARK, NEW JERSEY

MARCH 28, 1984

Ex. F-1

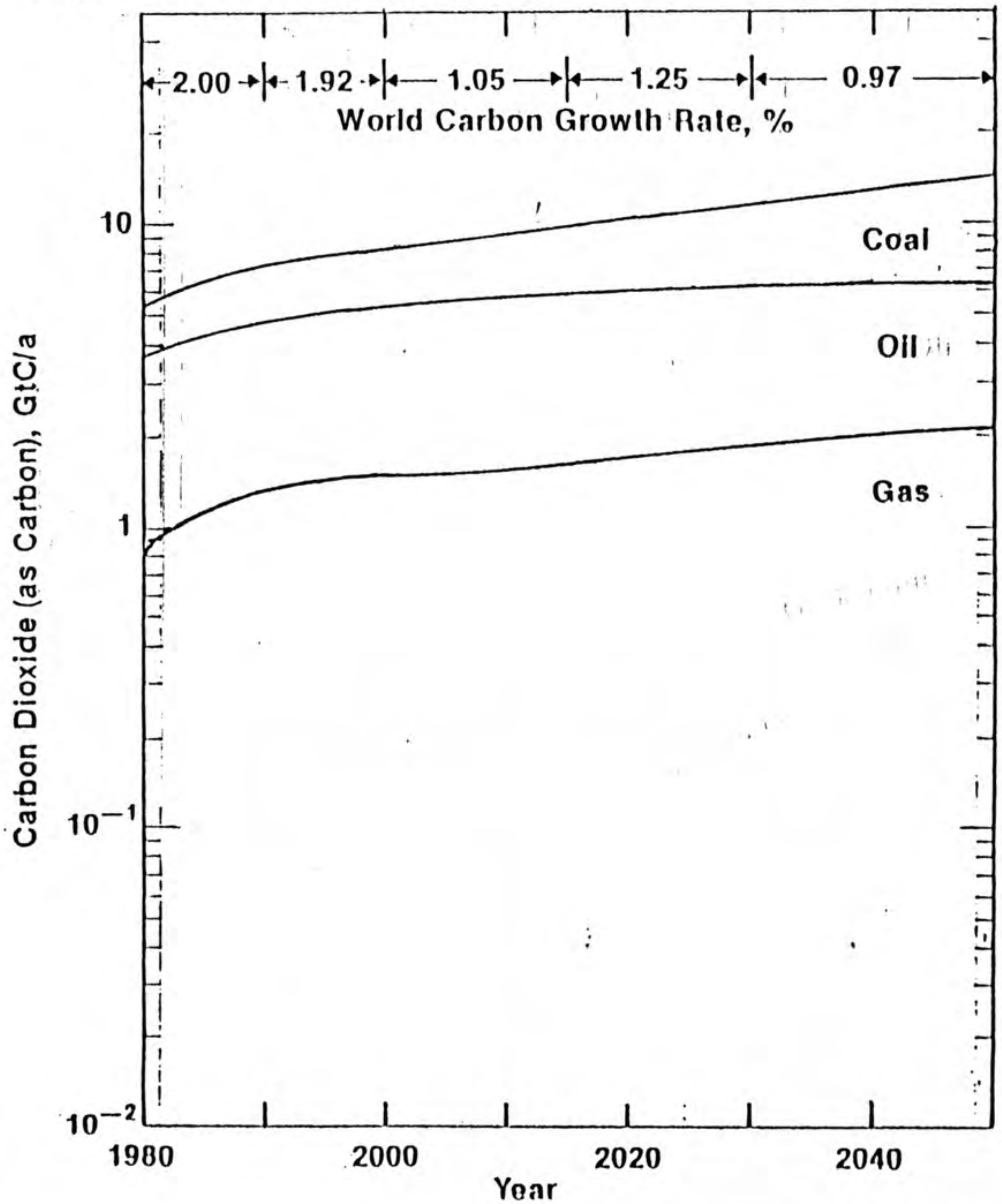
PRIMARY FOSSIL FUEL ENERGY CONSUMPTION
2030 STUDY



782114-32

Ex. F-2

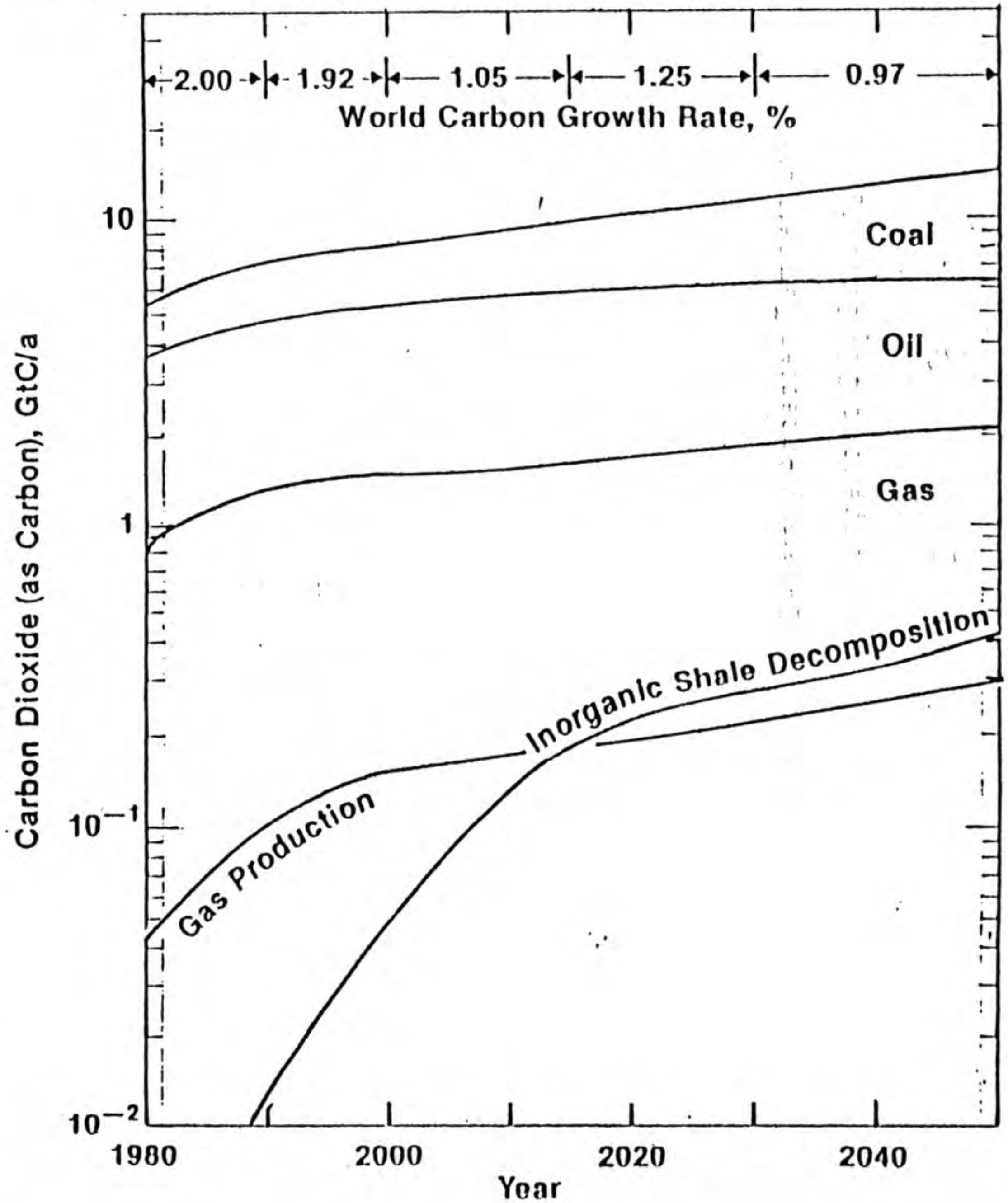
PROJECTED CARBON DIOXIDE (AS CARBON) FROM WORLD PRIMARY FOSSIL FUEL CONSUMPTION



782111-32

Ex. F-3

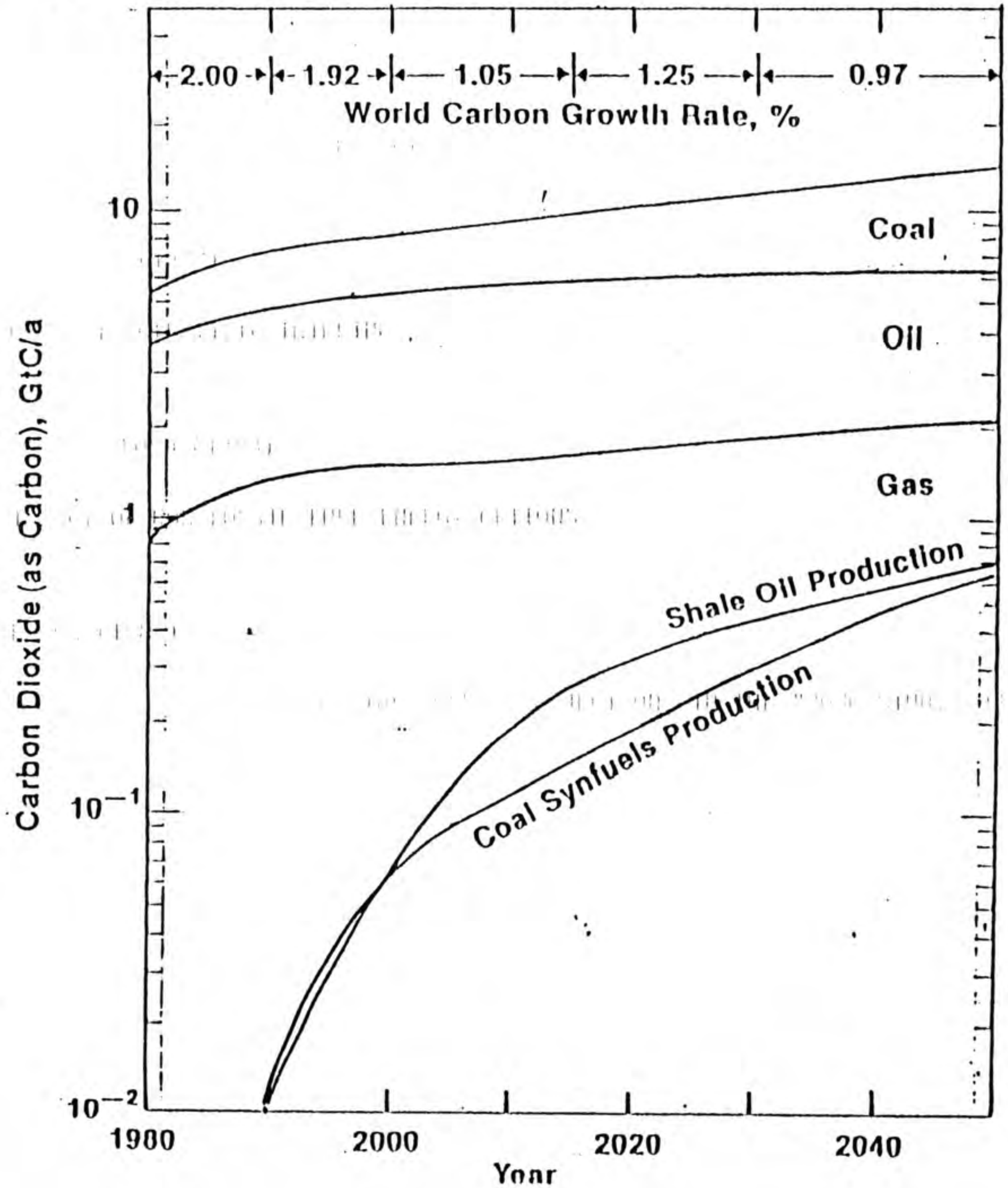
PROJECTED CARBON DIOXIDE (AS CARBON) FROM WORLD PRIMARY FOSSIL FUEL CONSUMPTION



Ex. F-4

782111-12

PROJECTED CARBON DIOXIDE (AS CARBON) FROM WORLD PRIMARY FOSSIL FUEL CONSUMPTION



Ex. F-5

RESULTS/EFFECTS

	EPA	NRC/NAS	MIT	EXXON
• TIME FOR CO_2 DOUBLING	2060	2075	-	2090
• AVERAGE TEMPERATURE RISE	3^oC	$\sim 2^oC$	$1.5\text{-}4.5^oC$	$1.3 - 3.1^oC$
• OTHER GASES IMPACT	-1.6 to 3.3^oC	$\sim 1^oC$	-	-
• SEA LEVEL RISE	150 cm, 2040 215 cm, 2100	70 cm 2080 ($3\text{-}4^oC$ rise)	-	-
• PRECIPITATION	POSSIBLE MAJOR CHANGES	DRIER MIDWEST	SIGNIFICANT, BUT UNPREDICTABLE	-
• AGRICULTURAL	PLUSES & MINUSES	BENEFITS WILL BALANCE DEBITS	SIGNIFICANT, BUT UNPREDICTABLE	-
• AIRBORNE CO_2 FRACTION	0.6 to 0.8	0.4 - 0.6	0.4 to 0.6	0.53
• IMPACT OF ALTERNATE ENERGY SOURCES	SMALL	INSENSITIVE	LARGE	INSENSITIVE

Ex. F-6

CONCLUSIONS/RECOMMENDATIONS

EPA

THERE IS LITTLE WE CAN DO EXCEPT LEARN TO ADAPT TO A WARMER CLIMATE.

LEGISLATION IS UNLIKELY TO HAVE MUCH EFFECT.

NRC/NAS

WE MUST RESOLVE UNCERTAINTIES THROUGH RESEARCH. ENERGY TAXES CAN HAVE AN IMPACT.

LEGISLATION IS PREMATURE.

MIT/STANFORD

WE MUST START TALKING TO POLICY MAKERS. SUGGEST EXTREME REDUCTION IN FOSSIL FUEL USE THROUGH CONSERVATION AND ALTERNATE TECHNOLOGIES USING ELECTRICITY. NUCLEAR CAN HAVE IMPACT.

INTERNATIONAL DEBATE ON LEGISLATION IS NEEDED.

EXXON

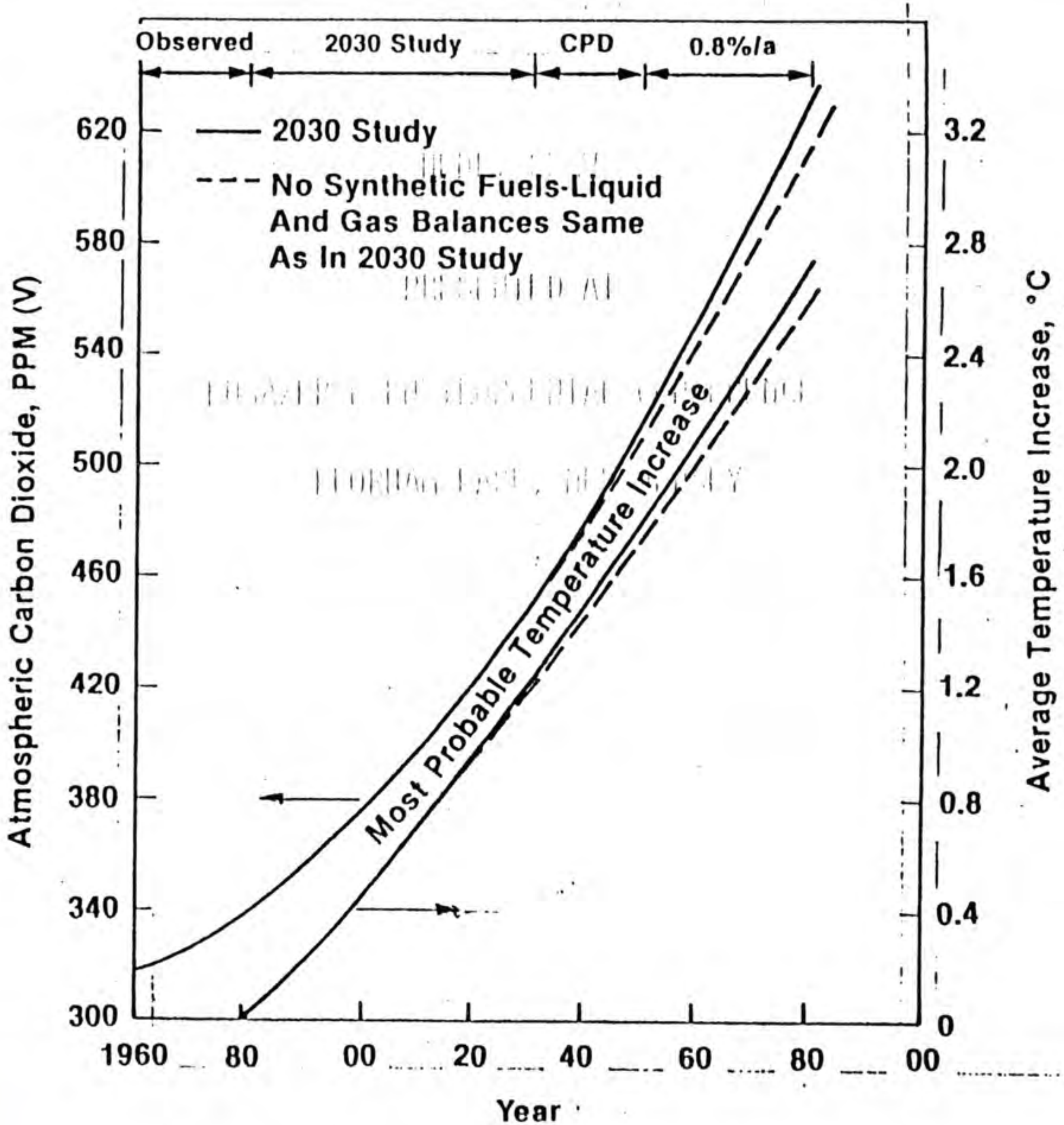
THERE IS ADEQUATE TIME TO STUDY THE PROBLEM.

LEGISLATION IS PREMATURE.

BACK - UP

Ex. F-8

GROWTH OF ATMOSPHERIC CO_2 AND INSTANTANEOUS GLOBAL TEMPERATURE INCREASE AS A FUNCTION OF TIME



Ex. F-9

782284-32

QUANTITY OF CO_2 PRODUCED FROM FUELS

MTC/EJ PRODUCT (% EFFICIENCY)

FUEL	PRODUCTION	REFINING	COMBUSTION	TOTAL	RATIO TO GAS
COAL	-	-	24.3	24.3	1.8
PETROLEUM					
GASOLINE	-	5.5(90)	18.8	24.3	1.8
FUEL OIL		1.9(95)	19.9	21.8	1.6
NATURAL GAS	-	-	13.5	13.5	1.0
COAL SYNTHETICS					
H-COAL (GASOLINE)	18.5(65)	17.2(75)	18.8	54.5	4.1
EDS (GASOLINE)	18.5(65)	13.5(80)	18.8	50.8	3.8
SNG	27 (60)	-	13.5	40.5	3.0
SHALE OIL (GASOLINE)	13.9(75)	6.5(88)	18.8	39.2	2.9
ELECTRICITY FROM COAL	67.4(36)			67.4	5.0

Ex. F-10

CO_2 GREENHOUSE AND CLIMATE ISSUES

AS PART OF CPPD's TECHNOLOGY FORECASTING ACTIVITIES IN 1981, I WROTE A CO_2 GREENHOUSE FORECAST BASED ON PUBLICALLY AVAILABLE INFORMATION. SOON THEREAFTER, S&T REQUESTED AN UPDATE OF THE FORECAST USING EXXON FOSSIL FUEL PROJECTIONS. THIS REQUEST WAS FOLLOWED LATE IN 1981 WITH A REQUEST BY CPD FOR ASSISTANCE IN EVALUATING THE POTENTIAL IMPACT OF THE CO_2 EFFECT IN THE "2030 STUDY". AFTER MEETING CPD'S SPECIFIC NEED, A FORMAL TECHNOLOGY FORECAST UPDATE WAS ISSUED TO S&T IN THE BEGINNING OF APRIL 1982. IT WAS SUBSEQUENTLY SENT FOR REVIEW TO THE EXXON AFFILIATES. THE PRIMARY FOSSIL FUEL VOLUMETRIC PROJECTIONS WERE CONVERTED TO AN ENERGY BASIS IN QUADS/YEAR, AS SHOWN ON THE
VG-1 FIRST VUGRAPH. SINCE SHALE LOSSES WERE NOT INCLUDED BY CPD, THEY WERE ESTIMATED AND ADDED TO OIL ENERGY. THE TOTAL CARBON CONTENT PER UNIT ENERGY OF THE U.S. RESOURCES OF COAL AND OIL SHALE WERE AVERAGED IN ORDER TO CALCULATE LBS. CO_2/MBTU FOR EACH RESOURCE:

	RATIO
OIL = 170 LBS. CO_2/MBTU	1.5
GAS = 115	1.0
COAL = 207	1.8

THESE NUMBERS WERE CHECKED AGAINST SOME INFORMATION ON WORLD RESOURCES AND FOUND TO BE ADEQUATE.

Ex. F-11

WE THEN ESTIMATED THE TOTAL CO_2 EMITTED FROM THE OXIDATION OF THESE

VG-2 FUELS, AS SHOWN IN THIS VUGRAPH. THIS IS A SEMILOG PLOT WHICH TENDS TO PICTORIALLY OVEREMPHASIZE THE IMPORTANCE OF GAS. WE CHOOSE THIS TYPE OF GRAPH TO ENABLE US TO SHOW CERTAIN DETAILS THAT WOULD BE HARD TO DETECT ON A LINEAR PLOT. THE RATE OF CO_2 EMISSIONS GROWS AT ABOUT A 20% HIGHER RATE THAN ENERGY. THIS IS DUE, IN PART, TO THE SHARP INCREASES IN THE USE OF COAL. OTHER FACTORS THAT CONTRIBUTE TO THE HIGHER CARBON GROWTH RATE ARE SHOWN ON

OL-1 (RED) OVERLAY #1 AND INCLUDE THE ENTRAINED CO_2 ASSOCIATED WITH NATURAL GAS IN GAS PRODUCTION GROWING FROM ABOUT 5% TO 15% IN 2050. SIMILARLY, U.S. OIL SHALES CONTAIN A FAIR AMOUNT OF CARBONATE-CONTAINING MINERALS CONSISTING PRIMARILY OF LIMESTONE AND DOLOMITE WHICH DECOMPOSE AS A FUNCTION OF RETORTING TEMPERATURE, FROM 25% AT RELATIVELY LOW TEMPERATURES SUCH AS CONVENTIONAL RETORTING TO 100% AT ELEVATED TEMPERATURES. WE ASSUMED, VERY CONSERVATIVELY, THAT 65% OF THE CARBONATE-CONTAINING MINERALS WOULD DECOMPOSE IN PRODUCING SHALE OIL. THE CO_2 IN GAS PRODUCTION WAS ADDED TO THE CO_2 EMISSIONS FROM GAS, AND THE SHALE CARBONATE DECOMPOSITION WAS ADDED TO CO_2 EMISSIONS FROM OIL. IN ADDITION, THE PROCESSING OF COAL AND OIL SHALE TO FUELS RESULTS IN A FAIR AMOUNT OF CO_2

OL-2 (BLUE) PRODUCTION. THIS IS SHOWN ON OVERLAY #2.

THE CLIMATIC EFFECT OF NOT HAVING A SYNFUELS INDUSTRY AND NOT EMITTING CO_2 IN NATURAL GAS PRODUCTION, I.E., SUBTRACTING THE CO_2 PRODUCED

VG-2 FROM THE SOURCES MENTIONED IN THE TWO OVERLAYS OF VUGRAPH #2, WOULD BE TO DELAY THE DOUBLING TIME BY ABOUT 5 YEARS.

OUR NEXT TASK IS TO CONVERT THE AMOUTN OF CO_2 EMITTED FROM FOSSIL FUEL OXIDATION INTO A PROJECTION OF HOW IT MAY IMPACT ON CLIMATE. THIS, HOWEVER, REQUIRES A NUMBER OF ASSUMPTIONS. FIRST OF ALL, WE MUST ESTIMATE HOW MUCH OF THE CO_2 STAYS IN THE ATMOSPHERE. THIS MUST BE CHECKED BY CONDUCTING A CARBON BALANCE AROUND THE EARTH. WE ASSUMED THAT ABOUT 1/2 OF THE CO_2 GENERATED FROM FOSSIL FUELS REMAINS IN THE ATMOSPHERE. THIS IS A CONSERVATIVE ASSUMPTION SINCE A FAIR AMOUNT OF CO_2 CAN BE TRACED TO DEFORESTATION. SECOND, WE MUST ESTIMATE HOW MUCH CO_2 EXISTED IN THE ATMOSPHERE PRIOR TO THE INDUSTRIAL REVOLUTION BECAUSE CO_2 CONCENTRATION WAS ASSUMED CONSTANT UP TO THAT TIME. THERE ARE TWO SCHOOLS OF THOUGHT, DEPENDING ON THE METHOD OF CHEMICAL ANALYSIS. ISOTOPE MEASUREMENTS IN TREE-RINGS INDICATE THAT THE ATMOSPHERE CONTAINED 260 TO 270 PPM CO_2 PRIOR TO THE INDUSTRIAL REVOLUTION. CORRECTIONS TO MEASUREMENTS ACTUALLY CARRIED OUT ABOUT THAT TIME INDICATE THE CONCENTRATION TO HAVE BEEN 290 TO 300 PPM CO_2. THIRD, WE MUST ESTIMATE WHEN THE CO_2 EFFECT WILL EXCEED THE CLIMATIC NOISE THRESHOLD OF 0.5^oC.

A GRAPH SHOWING ALL THESE ASSUMPTIONS IS REPRODUCED ON THE <u>LAST</u>
VG-3 <u>VUGRAPH</u>. MOST CLIMATOLOGISTS ASSUME THAT THE CO_2 EFFECT WILL BE DETECTABLE BY THE YEAR 2000. IF SO, WE MUST TAKE INTO ACCOUNT THAT IT TAKES ABOUT TWO DECADES TO EQUILIBRATE THE OCEANS TO A NEW TEMPERATURE. THUS, THE THRESHOLD WOULD OCCUR AT 340 PPM CO_2 AND WOULD CAUSE A TEMPERATURE RISE OF 3^oC IN 2090 WHEN THE CURRENT AMOUNT OF ATMOSPHERIC CO_2 WOULD DOUBLE, IF THE PRE-INDUSTRIAL CONCENTRATION HAD BEEN BETWEEN 290 AND 300 PPM. IF THE PREINDUSTRIAL CO_2 HAD BEEN BETWEEN 260 AND 270 PPM, THEN A DOUBLING WOULD CAUSE A 2^oC RISE IN GLOBAL AVERAGE TEMPERATURE. THESE VALUES FALL TOWARD THE LOWER END OF THE GENERALLY ACCEPTED TEMPERATURE RANGE FOR A DOUBLING OF 3 ± 1.5^oC, AND ARE CONSISTENT WITH THE RECENTLY PUBLISHED 50TH PERCENTILE LINE IN THE NAS REPORT.

Ex. F-13

A 2 TO 3^{o}C INCREASE IN GLOBAL AVERAGE TEMPERATURE CAN BE AMPLIFIED TO ABOUT 10^{o}C AT THE POLES. THIS COULD CAUSE POLAR ICE MELTING AND A POSSIBLE SEA-LEVEL RISE OF 0.7 METER BY 2080. THE TIME SCALE FOR SUCH A CATASTROPHE IS MEASURED IN CENTURIES. OTHER POTENTIAL EFFECTS ASSOCIATED WITH A HIGH ATMOSPHERIC CO_2 CONCENTRATION AND A WARMER CLIMATE ARE:

- REDISTRIBUTION OF RAINFALL
- POSITIVE AND NEGATIVE CHANGES IN AGRICULTURAL PRODUCTIVITY
- ACCELERATED GROWTH OF PESTS AND WEEDS
- DETRIMENTAL HEALTH EFFECTS
- POPULATION MIGRATION

SOCIETY MUST CAREFULLY STUDY THE PROBLEM IN ORDER TO ESTABLISH A DESIRABLE COURSE OF ACTION. WE CAN EITHER ADAPT OUR CIVILIZATION TO A WARMER PLANET OR AVOID THE PROBLEM BY SHARPLY CURTAILING THE USE OF FOSSIL FUELS. THE GENERAL CONCENSUS IS THAT SOCIETY HAS SUFFICIENT TIME TO TECHNOLOGICALLY ADAPT TO A CO_2 GREENHOUSE EFFECT.

OUR CONCLUSION WAS RECENTLY REAFFIRMED BY A NUMBER OF STUDIES WHICH RECEIVED WIDE PRESS PUBLICITY. THESE STUDIES INCLUDE THOSE OF THE EPA, NRC/NAS, AND MIT/NSF AND ARE SUMMARIZED IN THE NEXT 4 VU-GRAPHS.

Exhibit G

Central Files

PROPRIETARY INFORMATION

For Authorized Company Use Only

EXXON RESEARCH AND ENGINEERING COMPANY

P.O. BOX 101, FLORHAM PARK, NEW JERSEY 07932

EXXON ENGINEERING PETROLEUM DEPARTMENT
Planning Engineering Division

Cable: ENGREXXON, N.Y.

R. L. MASTRACCHIO
Manager
L. E. Hill
Senior Eng. Assoc.

October 16, 1979

Controlling Atmospheric CO_2

79PE 554

Dr. R. L. Hirsch:

The attached memorandum presents the results of a study on the potential impact of fossil fuel combustion on the CO_2 concentration in the atmosphere. This study was made by Steve Knisely, a summer employee in Planning Engineering Division.

The study considers the changes in future energy sources which would be necessary to control the atmospheric CO_2 concentration at different levels. The principle assumption for the CO_2 balance is that 50% of the CO_2 generated by fossil fuels remains in the atmosphere. This corresponds to the recent data on the increasing CO_2 concentration in the atmosphere compared to the quantity of fossil fuel combusted.

Present climatic models predict that the present trend of fossil fuel use will lead to dramatic climatic changes within the next 75 years. However, it is not obvious whether these changes would be all bad or all good. The major conclusion from this report is that, should it be deemed necessary to maintain atmospheric CO_2 levels to prevent significant climatic changes, dramatic changes in patterns of energy use would be required. World fossil fuel resources other than oil and gas could never be used to an appreciable extent.

No practical means of recovering and disposing of CO_2 emissions has yet been developed and the above conclusion assumes that recovery will not be feasible.

It must be realized that there is great uncertainty in the existing climatic models because of a poor understanding of the atmospheric/terrestrial/oceanic CO_2 balance. Much more study and research in this area is required before major changes in energy type usage could be recommended.

W. L. Ferrall

W. L. FERRALL

WLF:ceg
Attachment

Ex. G-1

c: J. F. Black
J. W. Herrmann
L. E. Hill
E. D. Hooper
F. J. Kaiser
R. L. Mastracchio
W. H. Mueller
H. Shaw
G. O. Wilhelm

CONTROLLING THE CO_2 CONCENTRATION IN THE ATMOSPHERE

The CO_2 concentration in the atmosphere has increased since the beginning of the world industrialization. It is now 15% greater than it was in 1850 and the rate of CO_2 release from anthropogenic sources appears to be doubling every 15 years. The most widely held theory is that:

- The increase is due to fossil fuel combustion
- Increasing CO_2 concentration will cause a warming of the earth's surface
- The present trend of fossil fuel consumption will cause dramatic environmental effects before the year 2050.

However, the quantitative effect is very speculative because the data base supporting it is weak. The CO_2 balance between the atmosphere, the biosphere and the oceans is very ill-defined. Also, the overall effect of increasing atmospheric CO_2 concentration on the world environment is not well understood. Finally, the relative effect of other impacts on the earth's climate, such as solar activity, volcanic action, etc. may be as great as that of CO_2.

Nevertheless, recognizing the uncertainty, there is a possibility that an atmospheric CO_2 buildup will cause adverse environmental effects in enough areas of the world to consider limiting the future use of fossil fuels as major energy sources. This report illustrates the possible future limits on fossil fuel use by examining different energy scenarios with varying rates of CO_2 emissions. Comparison of the different energy scenarios show the magnitude of the switch from fossil fuels to non-fossil fuels that might be necessary in the future. Non-fossil fuels include fission/fusion, geothermal, biomass, hydroelectric and solar power. The possible environmental changes associated with each scenario are also discussed.

CONCLUSIONS

As stated previously, predictions of the precise consequences of uncontrolled fossil fuel use cannot be made due to all of the uncertainties associated with the future energy demand and the global CO_2 balance. On the basis that CO_2 emissions must be controlled, this study examined the possible future fuel consumptions to achieve various degrees of control. Following are some observations and the principle conclusions from the study:

- The present trends of fossil fuel combustion with a coal emphasis will lead to dramatic world climate changes within the next 75 years, according to many present climatic models.

Ex. G-3

- The CO_2 buildup in the atmosphere is a worldwide problem. U.S. efforts to restrict CO_2 emission would delay for a short time but not solve the problem.

- Warming trends which would move the temperate climate northward may be beneficial for some nations (i.e., the USSR, see Figure 1) and detrimental for others. Therefore, global cooperation may be difficult to achieve.

- Removal of CO_2 from flue gases does not appear practical due to economics and lack of reasonable disposal methods.

- If it becomes necessary to limit future CO_2 emissions without practical removal/disposal methods, coal and possibly other fossil fuel resources could not be utilized to an appreciable extent.

- Even with dramatic changes in current energy resource use, it appears unlikely that an increase of 50% over the pre-industrial CO_2 level can be avoided in the next century. This would be likely to cause a slight increase in global temperatures but not a significant change in climate, ocean water level or other serious environmental efforts.

The <u>potential</u> problem is great and urgent. Too little is known at this time to recommend a major U.S. or worldwide change in energy type usage but it is very clear that immediate research is necessary to better model the atmosphere/terrestrial/oceanic CO_2 balance. Only with a better understanding of the balance will we know if a problem truly exists.

<u>Existing Data and Present Models</u>

Since the beginning of industrialization, the atmospheric carbon dioxide concentration has increased from approximately 290 ppm in 1860 to 336 ppm today. Atmospheric CO_2 concentrations have been recorded on a monthly basis by C. D. Keeling since 1958 at Mauna Loa Observatory in Hawaii (see Figure 2). Seasonal variations are clearly shown with the CO_2 concentrations lowest during the North American and Eurasian summers, due to increased photosynthetic activities. Over the last ten years, the atmospheric concentration has been increasing at an average rate of about 1.2 ppm/year.

The present consumption of fossil fuels releases more than 5 billion tons of carbon as CO_2 into the atmosphere each year. Data to date indicate that of the amount released approximately one-half is absorbed by the oceans. The other half remains in the atmosphere. There is some question as to whether the terrestrial biosphere is a sink, absorbing atmospheric CO_2, or a source of CO_2 emissions, due to man's land clearing activities. Current opinion attributes the atmospheric CO_2 increase to fossil fuels and considers the biosphere input to be negligible.

Figure 3 shows the carbon cycle with the ocean and the biosphere as sinks for approximately 50% of the fossil fuel emissions. Most models show the ocean to be a major sink while the biosphere appears to be a much smaller sink if it absorbs any CO_2 at all. It is clear from Figure 3 that the net atmospheric increase in CO_2 is quite small compared to the quantities of CO_2 exchanged between the atmosphere and the earth. This makes it very difficult to analyze the fossil fuel impact on the overall carbon cycle.

The fossil fuel resource is very large compared to the quantity of carbon in the atmosphere. Therefore, if one half of the CO_2 released by combustion of fossil fuels remains in the atmosphere, only about 20% of the recoverable fossil fuel could be used before doubling the atmospheric CO_2 content.

The concern over the increasing CO_2 levels arises because of the radiative properties of the gas in the atmosphere. CO_2 does not affect the incoming short-wave (solar) radiation to the earth but it does absorb long-wave energy reradiated from the earth. The absorption of long-wave energy by CO_2 leads to a warming of the atmosphere. This warming phenomenom is known as the "greenhouse effect."

A vast amount of speculation has been made on how increased CO_2 levels will affect atmospheric temperatures. Many models today predict that doubling the 1860 atmospheric CO_2 concentration will cause a 1^{o} to $5^{o}C$ global temperature increase (see Figure 4). Extrapolation of present fossil fuel trends would predict this doubling of the CO_2 concentration to occur about 2050. A temperature difference of $5^{o}C$ is equal to the difference between a glacial and an interglacial period. The temperature increases will also tend to vary with location being much higher in the polar region (see Figure 5). These temperature predictions may turn out too high or low by several fold as a result of many feedback mechanisms that may arise due to increased temperatures and have not been properly accounted for in present models.

These mechanisms include:

- <u>A decrease in average snow and ice coverage</u>. This is a positive feedback mechanism since it would result in a decrease of the earth's albedo (reflectivity) which would produce an added warming effect.

- <u>Cloud Cover</u>. This is considered the most important feedback mechanism not accounted for in present models. A change of a few percent in cloud cover could cause larger temperature changes than those caused by CO_2. Increased atmospheric temperature could cause increased evaporation from the oceans and increased cloud cover.

- <u>Ocean and Biosphere Responses</u>. As the CO_2 level is increased and the ambient temperature rises, the ocean may lose some of its capacity to absorb CO_2 resulting in a positive feedback. However, increased CO_2 levels could increase photosynthetic activities which would then be a negative feedback mechanism.

Ex. G-5

As evidenced by the balance shown in Figure 3, the atmospheric carbon exchange with the terrestrial biosphere and the oceans is so large that small changes due to these feedback mechanisms could drastically offset or add to the impact of fossil fuel combustion on the earth's temperature.

Appendix A gives one, but not unanimous, viewpoint of how the environment might change if the feedback mechanisms are ignored. The contribution that will ultimately be made by these feedback mechanisms is unknown at present.

Energy Scenarios for Various CO_2 Limits

Using the CO_2 atmospheric concentration data recorded to date, the correlation of these data with fossil fuel consumption and the proposed "greenhouse effect" models, this study reviews various world energy consumption scenarios to limit CO_2 atmospheric buildup. The concentration of CO_2 in the atmosphere is controlled in these studies by regulating the quantity of each type of fossil fuel used and by using non-fossil energy sources when required. The quantity of CO_2 emitted by various fuels is shown in Table 1. These factors were calculated based on the combustion energy/carbon content ratio of the fuel and the thermal efficiency of the overall conversion process where applicable. They show the high CO_2/energy ratio for coal and shale and the very high ratios for synthetic fuels from these base fossil fuels which are proposed as fuels of the future.

The total world energy demand used in these scenarios is based upon the predictions in the Exxon Fall 1977 World Energy Outlook for the high oil price case for the years 1976 to 1990. It is assumed that no changes in the sources of supply of energy could be made during this period of time. Case A, which has no restrictions on CO_2 emissions, follows the high oil price predictions until 2000.

Petroleum production and consumption is the same in each scenario. The high oil price case predictions are followed until 2000. After 2000 petroleum production continues to increase until a reserve to production ratio (R/P) equals ten to one. Production peaks at this point and then continues at a ten to one R/P ratio until supplies run out.

The consumption of coal, natural gas and non-fossil fuels (fission/fusion, geothermal, biomass, hydroelectric and solar power) vary with each scenario. Shale oil makes small contributions past the year 2000. It is not predicted to be a major future energy source due to environmental damage associated with the mining of shale oil, and also due to rather large amounts of CO_2 emitted per unit energy generated (see Table 1). If more shale oil were used, it would have the same effect on CO_2 emissions as the use of more coal. The fossil fuel resources assumed to be recoverable are tabulated in Appendix B.

Ex. G-6

A. No Limit on CO_2 Emissions

In this scenario no limitations are placed upon future fossil fuel use. The use of coal is emphasized for the rest of this century and continues on into the next century. The development and use of non-fossil fuels continue to grow but without added emphasis. Natural gas production continues at a slowly increasing rate until an R/P ratio of 7/1 is reached around 2030. Production after 2030 continues at a 7/1 ratio until reserves run out. Figure 6 shows the future energy demand for this scenario.

Figure 7 shows that the CO_2 buildup from this energy strategy is quite rapid. The yearly atmospheric CO_2 increase rises from 1.3 ppm in 1976 to 4.5 ppm in 2040. Noticeable temperature changes would occur around 2010 as the concentration reaches 400 ppm. Significant climatic changes occur around 2035 when the concentration approaches 500 ppm. A doubling of the pre-industrial concentration occurs around 2050. The doubling would bring about dramatic changes in the world's environment (see Appendix A). Continued use of coal as a major energy source past the year 2050 would further increase the atmospheric CO_2 level resulting in increased global temperatures and environmental upsets.

B. CO_2 Increase Limited to 510 ppm

This energy scenario is limited to a 75% increase over the pre-industrial concentration of 290 ppm. No limitations are placed on petroleum production. Natural gas production is encouraged beginning in 1990 to minimize coal combustion until non-fossil fuels are developed. Production of natural gas would increase until 2010 when an R/P ratio of 7/1 would be reached. Production would then continue at a R/P of 7/1 until supplies ran out. The development and use of nonfossil fuels are emphasized beginning the 1990's. Non-fossil fuels start to be substituted for coal in 1990's. Figure 8 shows the future energy demand by fuel for this scenario.

Figure 9 shows the atmospheric CO_2 concentration trends for this scenario. The lower graph shows the maximum yearly atmospheric CO_2 increase allowable for the 510 ppm limit. The yearly CO_2 increase peaks in 2005 when it amounts to 2.3 ppm and then steadily decreases reaching 0.2 ppm in 2100. A 0.2 ppm increment is equivalent to the direct combustion of 5.1 billion B.O.E. of coal. This would be approximately 2 to 3% of the total world energy demanded in 2100. (For more detail on the construction of Figure 9, see Appendix C.)

A comparison of the Exxon year 2000 predictions and this scenario's year 2000 requirements shows the magnitude of possible future energy source changes. The Exxon predictions call for nonfossil fuels to account for 18 billion B.O.E. in 2000. This scenario requires that 20 billion B.O.E. be supplied by non-fossil fuels by

2000. This difference of 2 billion B.O.E. is equivalent to the power supplied by 214-1000 MW nuclear power plants operating at 60% of capacity. If it were supplied by methane produced from biomass, it would be equivalent to 80,000 square miles of biomass at a yield of 50 ton/acre, heat value of 6500 Btu/dry pound and a 35% conversion efficiency to methane. Therefore even a 20% increase in non-fossil fuel use is a gigantic undertaking.

The magnitude of the change to non-fossil fuels as major energy sources is more apparent when scenarios A and B are compared in the year 2025. Scenario B requires an 85 billion B.O.E. input from non-fossil fuels in 2025. This is almost double the 45 billion B.O.E. input predicted in scenario A. This 35 billion B.O.E. difference is approximately equal to the total energy consumption for the entire world in 1970.

The environmental changes associated with this scenario wouldn't be as severe as if the CO_2 concentration were allowed to double as in scenario A. Noticeable temperature changes would occur around 2010 when the CO_2 concentration reaches 400 ppm. Significant climate changes would occur as the atmospheric concentration nears 500 ppm around 2080. Even though changes in the environment due to increased atmospheric CO concentrations are uncertain, an increase to 500 ppm would probably bring about undesirable climatic changes to many parts of the earth although other areas may be benefitted by the changes. (See Appendix A, part 1).

C. CO_2 Increase Limited to 440 ppm

This scenario limits future atmospheric CO_2 increases to a 50% increase over the pre-industrial concentration of 290 ppm. As in the previous case, no limitations are placed on petroleum production and increased natural gas production is encouraged. Much emphasis is placed on the development and use of non-fossil fuels. Non-fossil fuels are substituted for coal beginning in the 1990's. By 2010 they will have to account for 50% of the energy supplied worldwide. This would be an extremely difficult and costly effort if possible. In this scenario coal or shale will never become a major energy source. Figure 10 shows the future world energy demand by fuel for this scenario.

The atmospheric CO_2 concentration trends for this scenario are shown in Figure 11. To satisfy the limits of this scenario the yearly CO_2 emissions would have to peak in 1995 at 2.0 ppm, and then rapidly decrease reaching a value of 0.04 ppm in 2100. A 0.04 ppm maximum allowable increase means that unless removal/disposal methods for CO_2 emissions are available only one billion B.O.E. of coal may be directly combusted in 2100 (or 1.4 billion Barrels of Oil). This would be less than 1% of the total energy demanded by the world in 2100.

To adhere to the 440 ppm limit, non-fossil fuels will have to account for 28 billion B.O.E. in 2000 as compared to 20 billion B.O.E. in scenario B and 18 billion B.O.E. in scenario A. This difference between scenarios A and C of 10 billion B.O.E. is equivalent to over 1000, 1000 MW nuclear power plants operating at 60% of capacity. Ten billion B.O.E. is also approximately equivalent to 400,000 square miles of biomass at 35% conversion efficiency to methane. This is equivalent to almost one-half the total U.S. forest land.

By 2025 the 110 billion B.O.E. input from non-fossil fuels called for in this scenario is more than twice as much as the 45 billion B.O.E. input predicted in scenario A. This difference of 65 billion is approximately equal to the amount of energy the entire world will consume in 1980. In terms of power plants, 65 billion B.O.E. is equivalent to almost 7000, 1000 MW nuclear power plants operating at 60% of capacity.

An atmospheric CO_2 concentration of 440 ppm is assumed to be a relatively safe level for the environment. A slight global warming trend should be noticeable but not so extreme as to cause major changes. Slight changes in precipitation might also be noticeable as the atmospheric CO_2 concentration nears 400 ppm.

S. KNISELY

Ex. G-9

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Table 1

CO_2 EMISSIONS

Fuel	lb CO_2 Emitted* / 1000 Btu Fuel	% of Present CO_2 Output
SNG from Coal	0.35	0
Coal Liquids	0.32	0
Methanol from Coal	0.38	0
H_2 from Coal Gasification	0.38	0
Shale Oil	0.23	0
Bituminous Coal	.21	38%
Petroleum	.15	49%
Natural Gas	.11	13%
Fission/Fusion	0	0
Biomass	0	0
Solar	0	0

* Includes conversion losses where applicable.

Ex. G-11

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APPENDIX A

ECOLOGICAL CONSEQUENCES OF INCREASED CO_2 LEVELS

From:

Peterson, E.K., "Carbon Dioxide Affects Global Ecology," Environmental Science and Technology 3 (11), 1162-1169 (Nov '69).

1. Environmental effects of increasing the CO_2 levels to 500 ppm. (1.7 times 1860 level)

   - A global temperature increase of 3°F which is the equivalent of a 1°-4° southerly shift in latitude. A 4° shift is equal to the north to south height of the state of Oregon.
   - The southwest states would be hotter, probably by more than 3°F, and drier.
   - The flow of the Colorado River would diminish and the southwest water shortage would become much more acute.
   - Most of the glaciers in the North Cascades and Glacier National Park would be melted. There would be less of a winter snow pack in the Cascades, Sierras, and Rockies, necessitating a major increase in storage reservoirs.
   - Marine life would be markedly changed. Maintaining runs of salmon and steelhead and other subarctic species in the Columbia River system would become increasingly difficult.
   - The rate of plant growth in the Pacific Northwest would increase 10% due to the added CO_2, and another 10% due to increased temperatures.

2. Effects of a doubling of the 1860 CO_2 concentration. (580 ppm)

   - Global temperatures would be 9°F above 1950 levels.
   - Most areas would get more rainfall, and snow would be rare in the contiguous states, except on higher mountains.
   - Ocean levels would rise four feet.
   - The melting of the polar ice caps could cause tremendous redistribution of weight and pressure exerted on the earth's crust. This could trigger major increases in earthquakes and volcanic activity resulting in even more atmospheric CO_2 and violent storms.
   - The Arctic Ocean would be ice free for at least six months each year, causing major shifts in weather patterns in the northern hemisphere.

Ex. G-12

- The present tropics would be hotter, more humid, and less habitable, but the present temperature latitude would be warmer and more habitable.

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APPENDIX B

FOSSIL FUEL RESOURCES

Oil	-	Assume 1.6 trillion barrels of oil potentially recoverable as of 1975 (assuming the future recovery rate to be 40%). The minimum allowable Reserve to Production (R/P) ratio is ten one.
Shale Oil	-	Potential of 3.0 trillion B.O.E. but assuming 1977 technology only 200 billion B.O.E. actually recoverable.
Natural Gas	-	Approximately 1.6 trillion B.O.E. potentially recoverable. Minimum allowable R/P = 7.1.
Coal	-	Potential recoverable reserves equal approximately 12 trillion B.O.E. assuming a conservative 25% recoverability.

Ex. G-14

APPENDIX C

CONSTRUCTION OF SCENARIOS B AND C
(Scenario A requires no CO_2 emissions control)

1. Scenario B

The CO_2 concentration vs. year curve in Figure 9 was generated by the following equation:

after 1970 (t = 0), then

$$*C = 292 \text{ ppm} + 219 \text{ ppm}/[1 + 5.37 \exp.(-t/24 \text{ years})]$$

where C = concentration in ppm

The curve on the lower section of Figure 9, atmospheric CO_2 increase vs. years, is generated by finding the difference in the concentrations of successive years. This curve gives the maximum yearly increases allowable to stay within the limits placed on this scenario. The amount of fossil fuel that may be consumed in any given year can then be calculated by the lower curve. For example:

In 2100 the maximum allowable CO_2 increase equals 0.2 ppm.

This is equivalent to:

$$\frac{2 \text{ ppm}}{} \times \frac{2.1 \times 10^9 \text{ ton C}}{1 \text{ ppm}} \times \frac{2000 \text{ lb}}{\text{ton}} \times \frac{44 \text{ lb } CO_2}{12 \text{ lb C}} = 3.1 \times 10^{12} \text{ lb } CO_2$$

3.1×10^{12} lb CO_2 may be released by the combustion of:

for coal: $$\frac{3.1 \times 10^{12} \text{ lb } CO_2}{} \times \frac{1000 \text{ Btu}}{.21 \text{ lb } CO_2} \times \frac{1 \text{ B.O.E.}}{5.8 \times 10^6 \text{ Btu}}$$

= 2.5 billion B.O.E. of coal

This scenario is based on the assumption that 50% of CO_2 released each year will always be absorbed by the ocean and the rest will remain in the atmosphere.

*Derived from an equation presented by U. Siegenthaler and H. Oeschger (1978) (see references).

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2. Scenario C

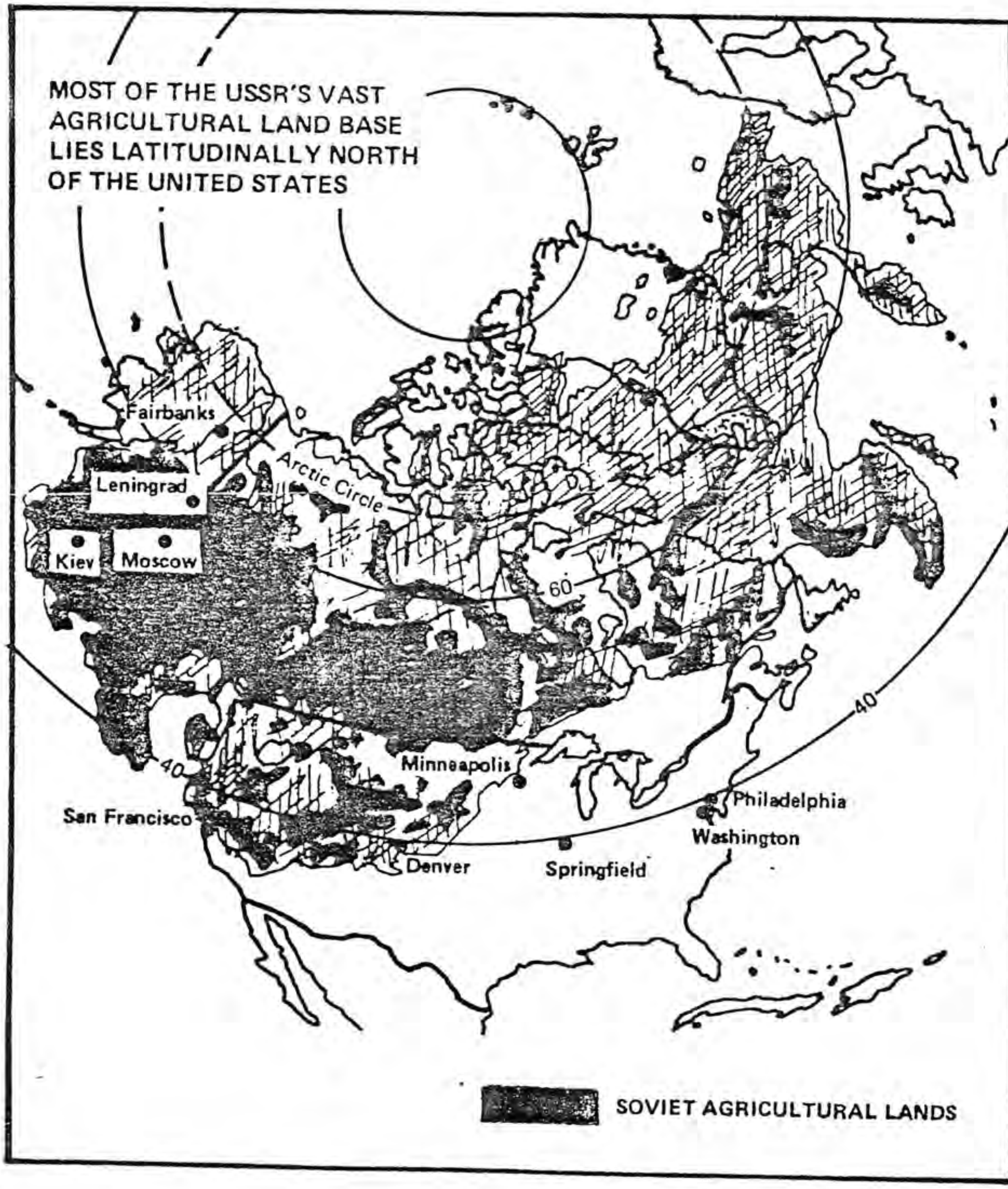
The equation for the generation of Figure 11 is derived to be,

after 1970 ($t = 0$), then

$$*C = 292 \text{ ppm} + 146 \text{ ppm}/[1 + 3.37 \exp.(-t/20 \text{ years})]$$

This scenario is the same as Scenario B only with different limits.

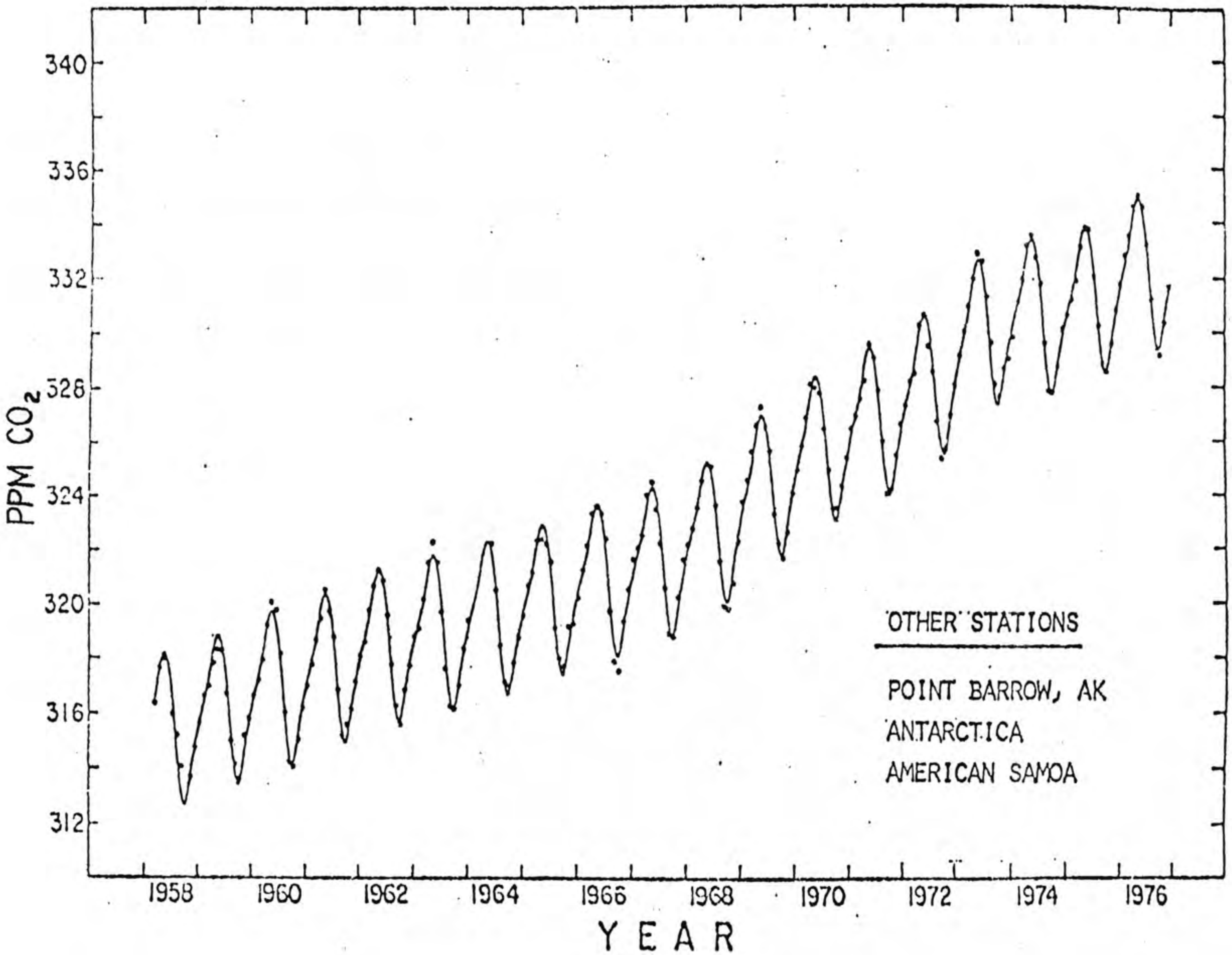
Figure 1



Ex. G-17

Figure 2

CONCENTRATION OF ATMOSPHERIC CO_2 AT MAUNA LOA OBSERVATORY, HAWAII



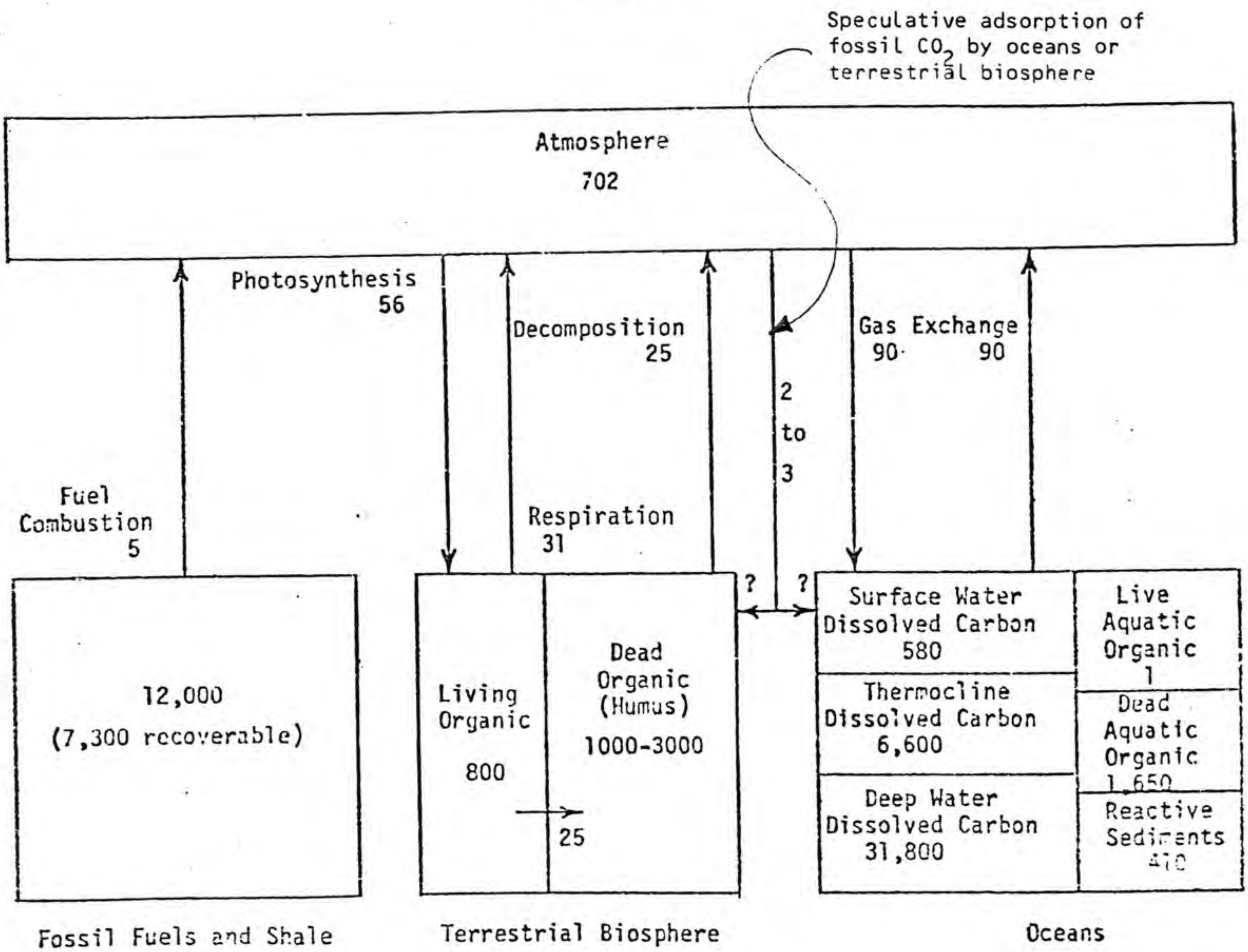
Ex. G-18

Figure 3

The Carbon Cycle

Current

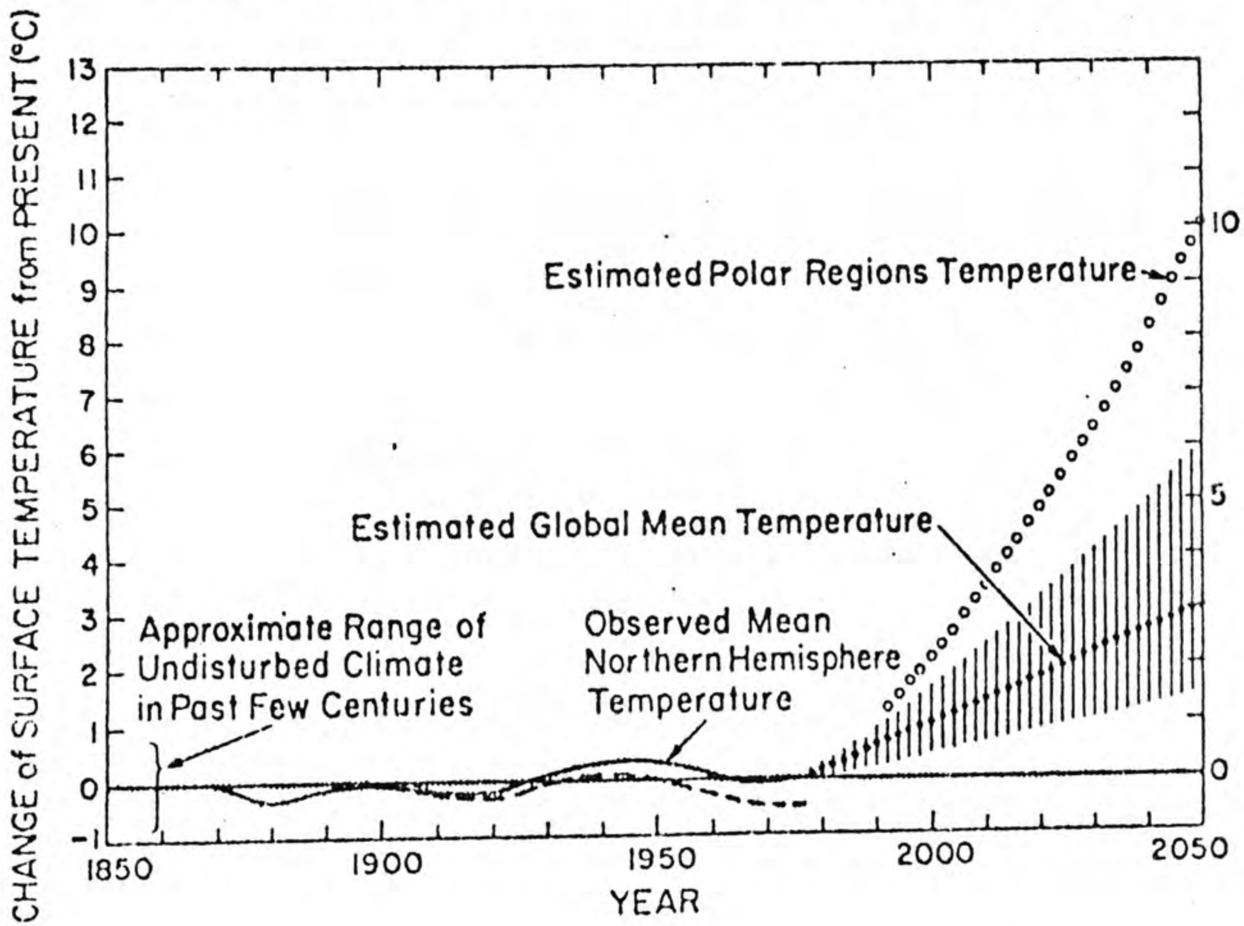
Fluxes in Gt/a
Pool sizes in Gt



Ex. G-19

Figure 4

HOW PREDICTED ΔT COMPARES WITH RECENT TEMPERATURES



Ex. G-20

Figure 5

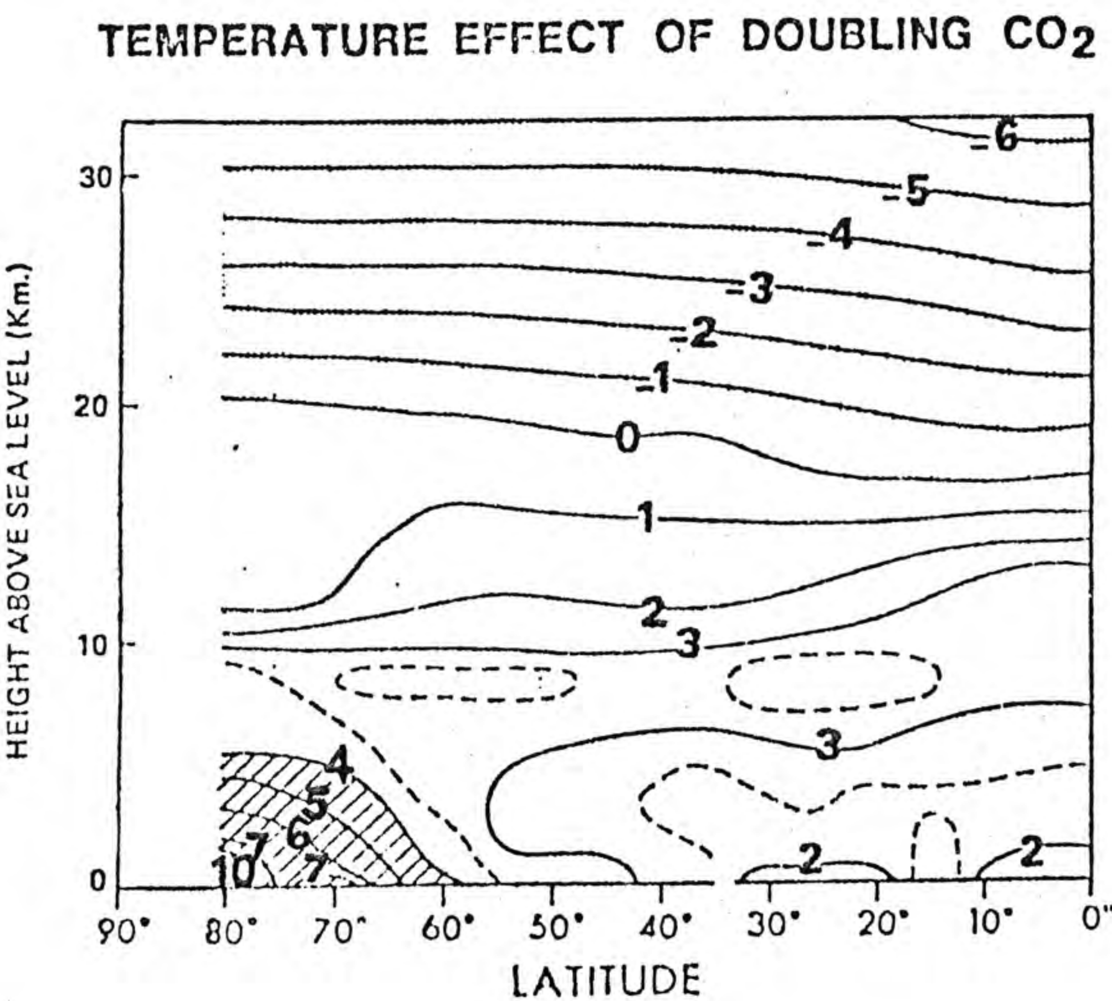


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Figure 6

WORLD ENERGY DEMAND BY FUEL

UNLIMITED CO_2 INCREASE
(COAL EMPHASIS)

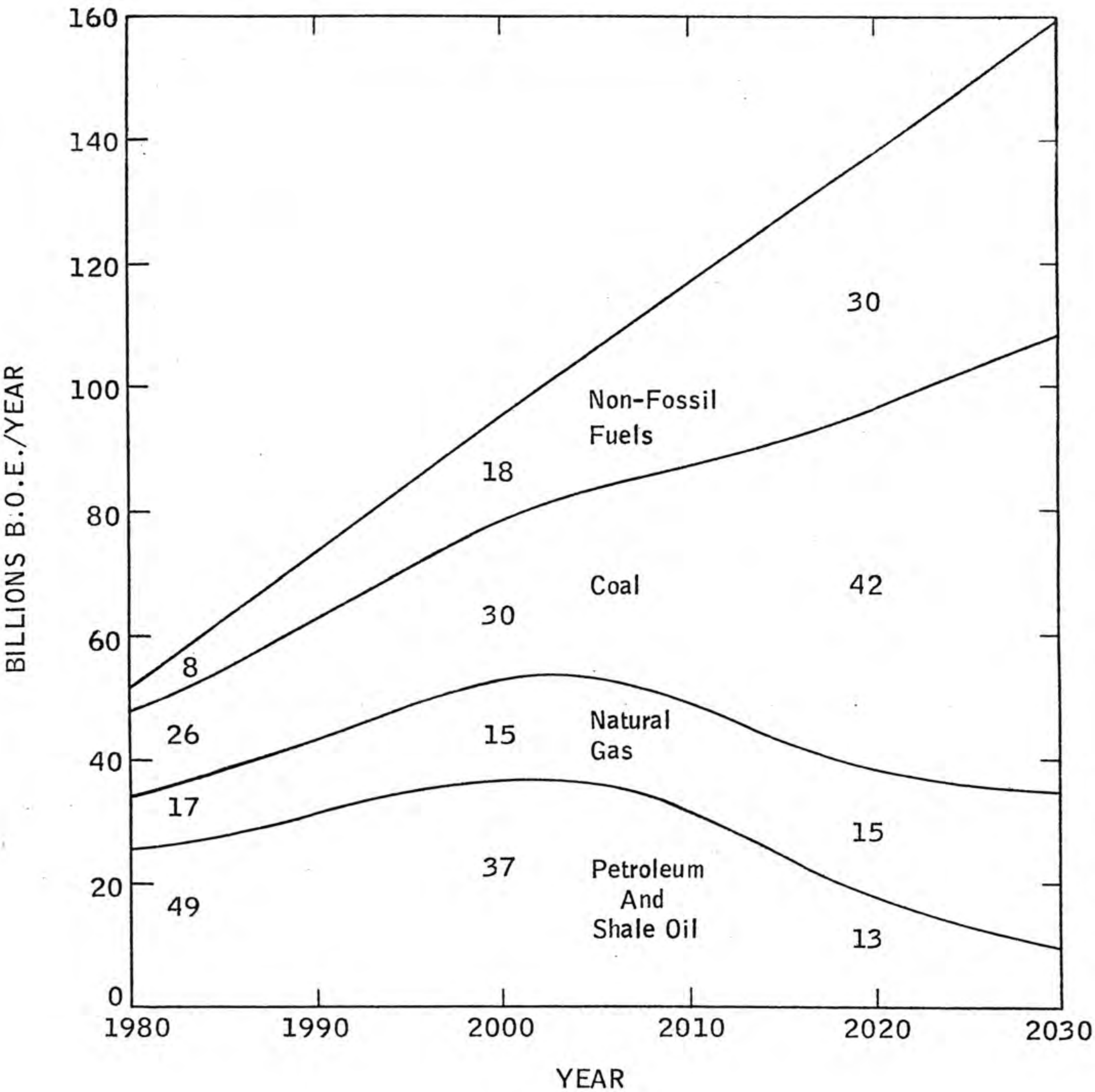

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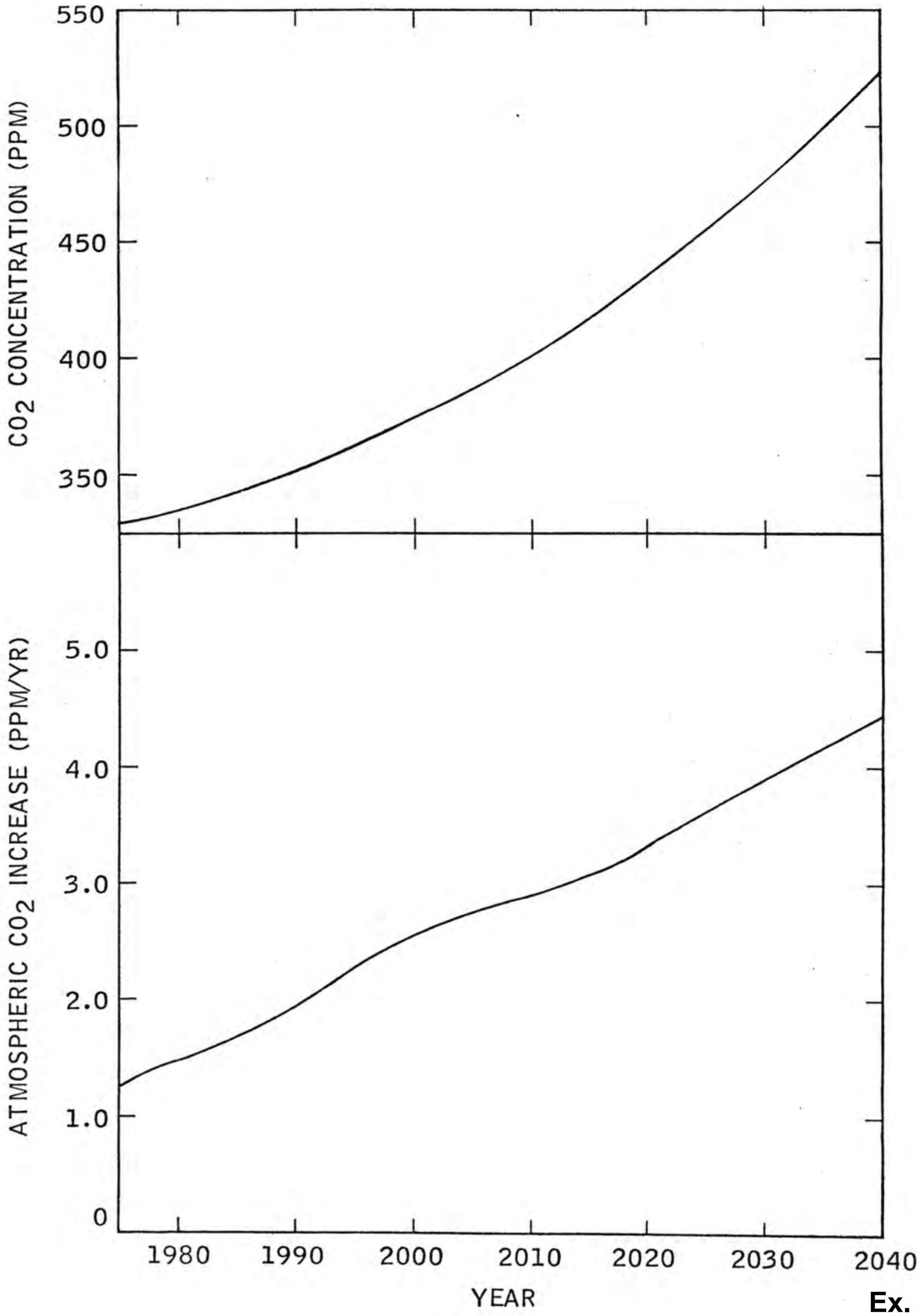
Figure 7

CO_2 IN ATMOSPHERE

RATE OF CO_2 BUILDUP

UNLIMITED INCREASE



Ex. G-23

Figure 8

WORLD ENDERGY DEMAND BY FUEL
LIMITED TO A 75% CO_2 INCREASE

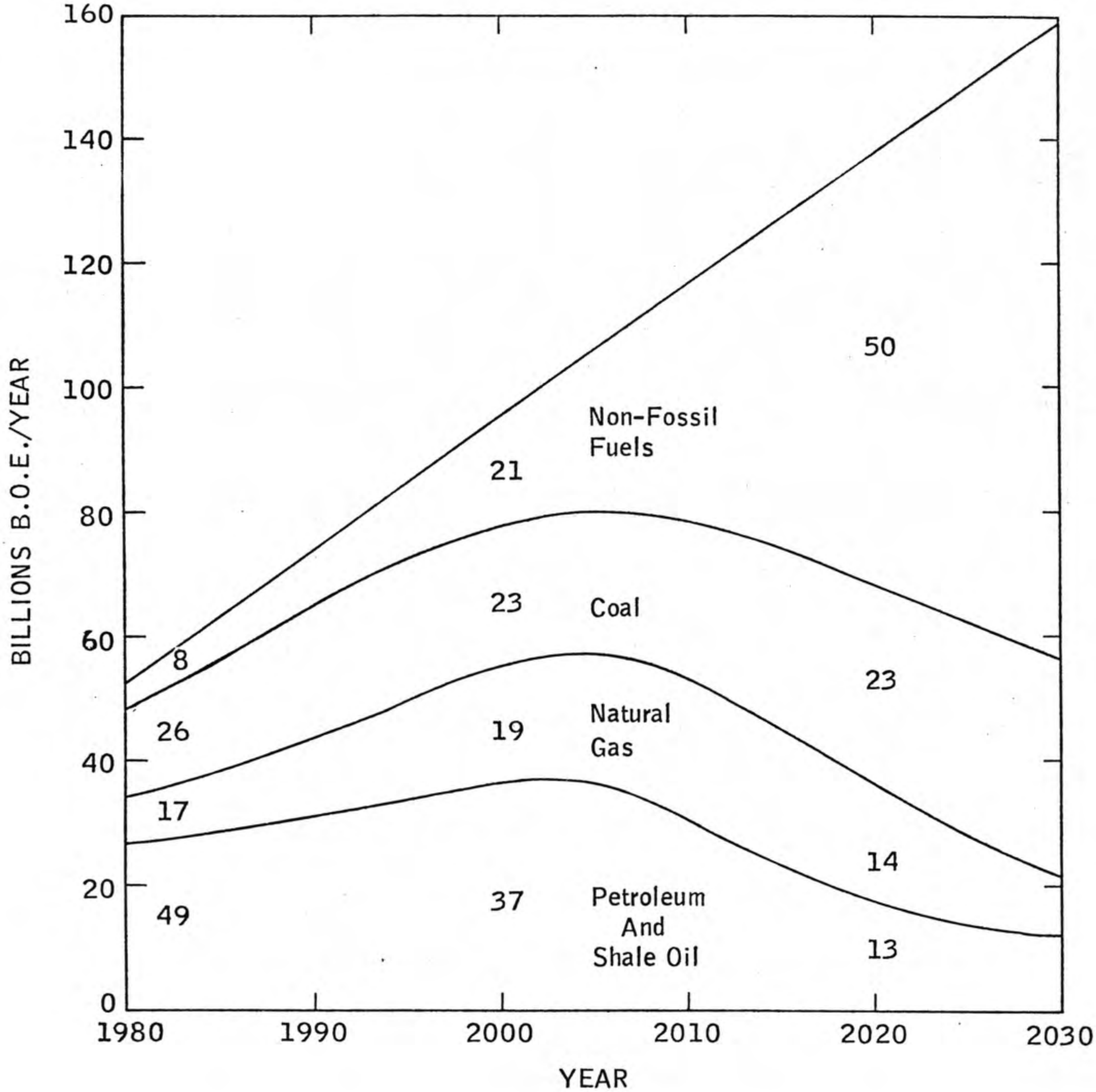


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Figure 9

CO_2 IN ATMOSPHERE

RATE OF CO_2 BUILDUP
LIMITED TO 75% INCREASE

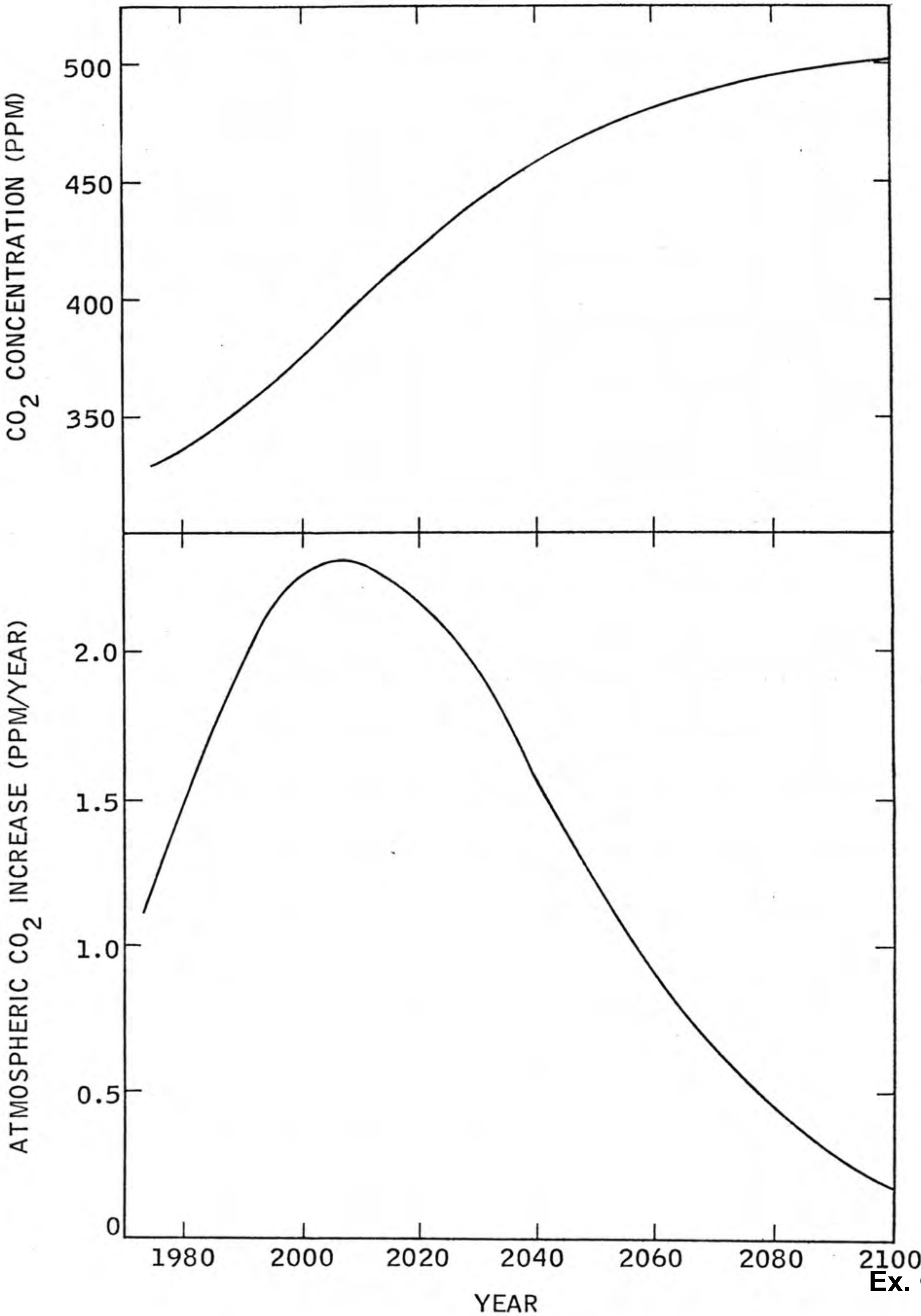

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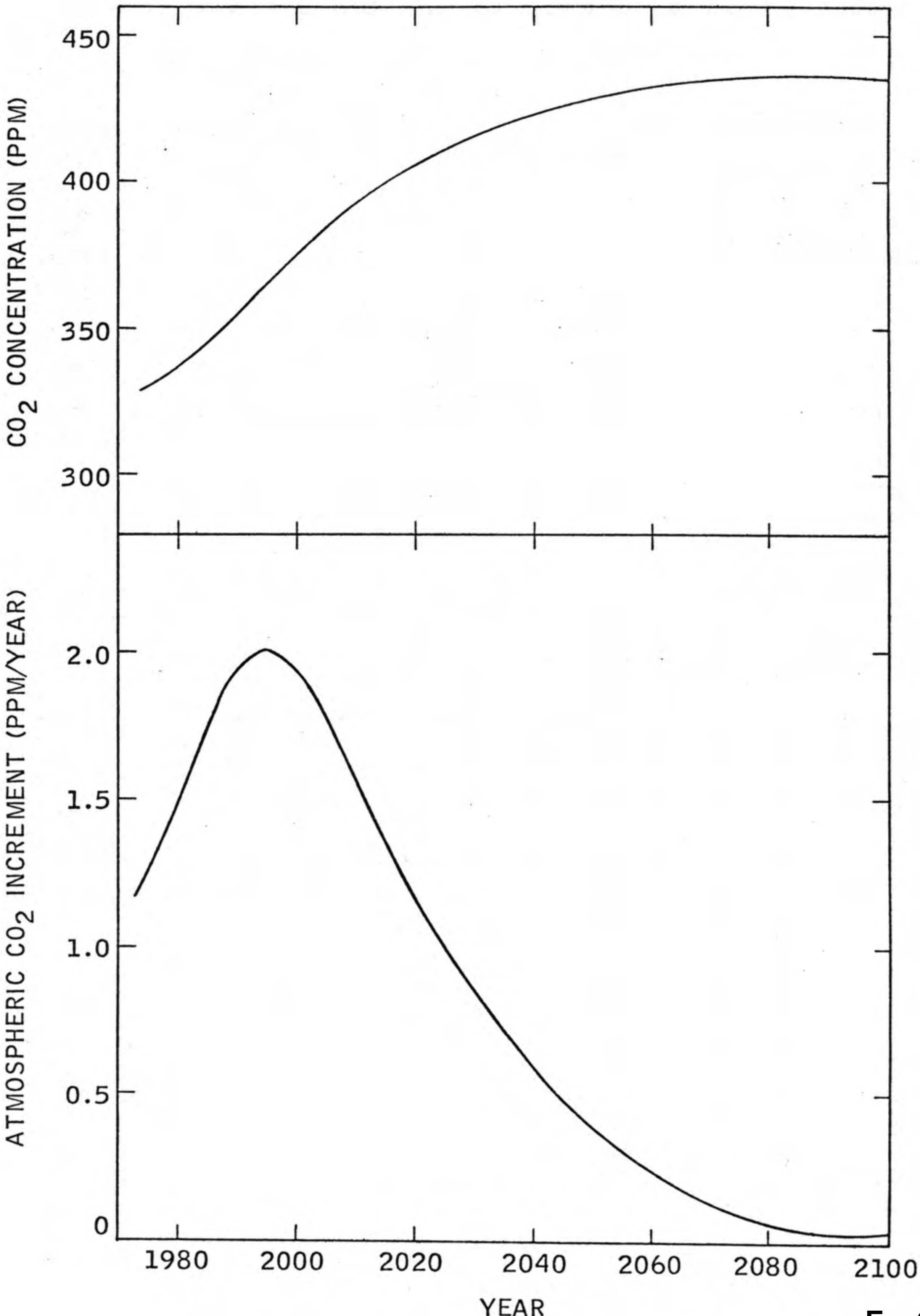
Figure 11

CO_2 IN ATMOSPHERE
RATE OF CO_2 BUILDUP



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