Council on Environmental Quality: "Global Energy Features and the Carbon Dioxide Problem," 1980

WOCOL WORLD COAL STUDY

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CLW - Info mike

June 25, 1980

Mr. Gus Speth
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Dear Gus:

Thank you very much for sending me a review draft of CEQ's "Global Energy Futures and the Carbon Dioxide Problem". I for one applaud CEQ's lead role in advocating a comprehensive and critical review of the implications of fossil fuel expansion on the global climate.

But I must say to you, Gus, that the CEQ scientific base described in the draft appears to be so flawed that CEQ's concern is likely to be summarily dismissed out of hand unless the supporting analysis is substantially upgraded. Let me cite two examples which led to my reaction:

(1) <u>CO_2 Emissions</u>: A footnote on page 25 makes the surprising admission that the CEQ model assumes for all fossil fuel an average CO_2 emission rate corresponding to that of coal. Of course this overstates the CO_2 emitted from oil by 25% and from gas by 75%. Using this simplistic assumption, for example, would upwardly bias total carbon emissions world-wide in 1979 by 22%, which is greater than the 15% increase in the amount of carbon dioxide in the atmosphere during the last century.

(2) <u>Temperature Effects</u>: The study's assumption that a doubling of carbon dioxide concentrate will yield an average 3°C temperature rise seems higher by about 40% of mid-range estimates by others, for example, the work of Kan Chen which uses a range of 1.5 - 2.9°C.

Without being qualified to retrace the analysis track, I can only assume that CEQ's upward bias on CO_2 effects explains the apocalyptic projection that to "limit" CO_2 concentration to a doubling requires fossil fuel use growth of only 1.6%/yr in the 1980's, falling to 1.3%/yr in the 90's and to zero by 2030. This is simply not compatible with Chen's conclusion that, under the <u>most pessimistic assumptions</u> about the carbon cycle, a doubling would not be reached until 2050 with fossil energy growth of 2%/yr. Under optimistic assumptions, Chen implies that with 2%/yr growth, a doubling may never occur and certainly won't in the next century.

Mr. Gus Speth
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But perhaps the most troubling part of the CEQ paper is the lack of recognition of the enormous uncertainties about the carbon cycle, which overwhelm any assumptions about fossil energy use. As Chen says, "The results of the temperature range analysis indicate that at this time there is noway to justify any suggestions of immediate curtailment of coal or fossil fuel use on the grounds of CO_2 effects alone".

Finally, let me say that I think the World Coal Study supports the contention
CEQ contribution that energy conservation will be central in ameliorating this and other environmental effects of expanded coal use. We found that total OECD fossil energy growth would be only 1.3%/yr over the 1977-2000 period, despite the growth of the coal component at 5%/yr. This is a principal reason for our optimism that coal can provide the bridge to the
two
future, for the next decades at least, and that "the present knowledge of possible carbon dioxide effects on climate does not justify delaying the expansion of coal use."

Very truly yours,

J. Michael Gallagher

J. Michael Gallagher
Technical Director
World Coal Study

Enclosures: Correspondence between J.M. Gallagher and K. Chen
cc: Professor Kan Chen

JMG/ssw

CLW
CEQ report. Jim
sending letter

DRAFT

GLOBAL ENERGY FUTURES AND THE CARBON DIOXIDE PROBLEM

Mike –
Good letter
Speth should
pause.
C

COUNCIL ON ENVIRONMENTAL QUALITY

Executive Office of the President

Washington, D.C.

March, 1980

REVIEW DRAFT

NOT FOR REFERENCE OR CITATION

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DRAFT

I. INTRODUCTION: THE CARBON DIOXIDE PROBLEM AND THE IMPLICATIONS OF DELAY

The carbon dioxide (CO_2) concentration in the earth's atmosphere is known to have increased about seven percent since 1958 and is estimated to have increased 15 to 25 percent since the beginning of the industrial period (about 1850) (1-4).* A major contributor of CO_2 to the atmosphere is the combustion of fossil fuels (5). Almost all current estimates of global energy use for the next 30 to 40 years indicate that fossil fuel will be used at rates that will cause CO_2 levels to continue to increase markedly (6). X
According to generally accepted geophysical calculations, CO_2 increases of these proportions will almost surely lead X
to significant changes in the earth's climate-- changes which may have adverse consequences such as reducing agricultural productivity over large areas and eventually increasing the sea level 5 to 6 meters (7-14).

The steadily rising global CO_2 concentration and the possibly adverse consequences are a source of increasing concern to scientists and policymakers (15). This report addresses the carbon dioxide problem from the standpoint of energy policy and concludes that we can afford to ignore the CO_2 problem in energy policy decisionmaking only at great

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* The present concentration of CO_2 is about 335 parts per million (ppm). The preindustrial level is estimated to lie within the range of about 270-290 ppm.

risk. As time passes and atmospheric CO_2 concentrations increase, the actions required to reduce climatic effects become increasingly more difficult to undertake. This report focuses on the reasons for this difficulty, the possible climatic effects of increased atmospheric CO_2, and the heavy reliance on mathematical models that is necessary in making important policy decisions. This report also provides estimates of atmospheric CO_2 concentrations for alternative energy use scenarios and examines the implications of these estimates for the use of fossil and nonfossil fuels.] X

The presence of carbon dioxide in the atmosphere creates a "greenhouse effect" by letting incoming short-wave solar radiation pass through to the earth, while partially absorbing outgoing longwave heat radiation. As the concentration of CO_2 increases, more radiated heat is trapped, and the lower atmosphere, on the average, becomes warmer (1-4).] X

It is estimated that doubling the atmosphere's CO_2 concentration over preindustrial levels will increase the average temperature of the atmosphere by 3.0 $\pm$ 1.5 degrees Celsius (or 5.4 $\pm$ 2.7 degrees Fahrenheit) in the middle latitudes and as much as 7 to 10^{o} C at the poles (14, 16). A temperature rise of this magnitude above the current average temperature would take the world's climate outside the range that has prevailed for the last several hundred thousand years (3, 17). If world fossil fuel use continues to increase at the long-term historical rate of 4 percent,

Ken Chen says range is 1.5-3

-4-11°

X

1973 break

X

CO_2 concentrations could double within a few decades, leading to a global surface temperature increase and to a significant reduction in the temperature differential between the equator and the poles, which would produce changes in regional climates.*

Wind direction and speed, ocean currents, and precipitation patterns would be altered. These climatic changes would cause significant socioeconomic and other effects. For example, the shift in crop patterns that could result from a large and comparatively sudden change in climate could have serious consequences -- capital infrastructures could be rendered obsolete, and increased soil aridity could result in the creation of new dustbowls. Coastal inundation could force eventual evacuation of lands now considered to be among the world's most desirable. While by no means certain, these are grave possibilities to consider. Some areas, however, might experience beneficial effects, such as enhanced agricultural output and reduced heating requirements (2, 18). In spite of the uncertainties, however, the possible adverse effects of global climate change appear to far outweigh the possible benefits (2, 11, 19, 20).

Four global reserviors contain most of the world's carbon; they are the oceans, the atmosphere, fossil fuels and the biosphere. The net result of complex flow patterns and exhange rates of carbon among these reservoirs is a

---

* There are other climate factors of potential global significance that could alter the climate effects caused by CO_2 build-up. These include increased volcanic activity and changes in the sun's energy output.

growth rate of atmospheric CO_2 corresponding to the atmosphere's retention of about half of the CO_2 produced by the burning of fossil fuels (5, 8, 21, 22). Some studies have postulated that global deforestation might be contributing as much CO_2 to the atmosphere as fossil fuels (23). Cutting down trees reduces take-up of CO_2 for photosynthesis, and the decay of trees and vegetation returns much of the stored CO_2 to the atmosphere. More recent work suggests that the biosphere is currently neither significantly adding to the world's CO_2 budget (serving as a source) or subtracting from it (serving as a sink). These recent studies conclude that regrowth of previously cut forests and the production of charcoal by forest fires is trapping enough carbon roughly to balance the release of CO_2 to the atmosphere by deforestation (5, 24, 29).

uncertain

It has been estimated that approximately 52% $\pm$ 4% of the CO_2 released by fossil fuel burning is retained by the atmosphere. The remaining 48% is distributed among the other reservoirs: about 37% to the oceans and 2% to shallow water sediments, leaving 9% still unaccounted for -- a possible indication that the biosphere is at least a minor sink for CO_2 (5).

Because fossil fuel combustion is the major contributor to the buildup of CO_2 in the atmosphere, an assessment of how and at what cost global CO_2 production can be controlled must focus on energy policies and use patterns. It is essential to make this assessment now -- before we can be empirically certain that significant climatic changes are occurring.

It seems reasonably clear that the basic uncertainties will not be resolved in the near future. In addition, it will probably require at least twenty years to confirm that observed climate changes are due to increased levels of atmospheric CO_2, rather than the result of normal climatic fluctuations (25). However, by the time CO_2-induced climatic effects become clearly visible, two results will probably have occurred.

The nations of the world are likely to have committed themselves to an energy future in which fossil fuel combustion plays an increasing role. For both political and economic reasons, once a large-scale commitment to increased use of fossil fuel has begun, it will be hard to reverse, even if climatic changes make reversal appear necessary (26).

?

natural age

Also, over that same period, the world would have produced still higher atmospheric concentrations of CO_2, which would continue to affect climate long after anthropogenic releases of CO_2 are reduced. For example, if fossil fuels were used at the historical growth rate of 4 percent per year, atmospheric CO_2 would be twice the preindustrial level by about 2025 (10). If other factors that could affect climate remain unchanged, during this period of increased fossil fuel use and CO_2 emissions, the oceans would have stored a significant amount of thermal energy.

2%

enormous uncertainty

Thus, once it were confirmed that CO_2-induced climate effects were occurring, it would first be necessary to reduce atmospheric CO_2 and then to dissipate the heat stored in the oceans, in order to reverse the climate effects. Throughout this period of change and recovery, the world would continue to suffer from adverse climatic consequences caused by higher global temperatures. Indeed, it would probably take several hundred years to regain a climate similar to our present climate, which forms the basis of socioeconomic patterns in the world today (27). Indeed, given the complexity of the global climate system, it might be impossible to return to a state approaching present conditions.

II. EFFECTS OF INCREASED CONCENTRATIONS OF CO_2

There is little empirical basis on which to predict the climatic consequences of increased atmospheric CO_2 concentrations, because the expected increases are unprecedented in the modern history of climate. Thus, the response of the world's climate to elevated CO_2 levels must be deduced from theoretical models that attempt to simulate the behavior of the real climate system and by studies of actual climatic changes associated with elevated temperatures in the distant past (1, 3, 18, 28).

Models of varying degrees of sophistication have been used to predict the temperature changes resulting from increased CO_2 concentration, but all are limited in their ability to include effects from various complex feedback mechanisms and to compensate for natural cyclic variations in temperature and climate. The climatic effects of recent increases in CO_2 concentrations have not been detected unambiguously (25, 28, 30). Thus, the accuracy of the models' predictive capability cannot be verified. Nevertheless, there is a broad consensus among climatologists that these models provide at least a rough estimate of the temperature changes to be expected from continuously increasing CO_2 levels. The failure to treat fully certain "feedback mechanisms" (described below) has led some climatologists to question the accuracy of the models. But the consensus, as summarized in the 1979 National Academy of Sciences Study, "Carbon Dioxide and Climate: A Scientific Assessment," is that, other

Do any models predict global cooling of last 40 yrs.?

things being equal, no combination of countervailing factors will reverse the conclusion that a doubling of the atmosphere's CO_2 concentration will cause global warming and significant climate changes (2, 14).

A. Temperature Effects

The most direct climatic effect of increasing atmospheric concentrations of CO_2 is the increase in the temperature of the lower atmosphere, which envelops the earth. The "greenhouse effect," which raises the surface temperature of the land and oceans works in the following way: shortwave solar radiation from the sun passes through CO_2 to the earth, but longer-wave infrared (heat radiation) emitted by the earth is partially absorbed by CO_2. As the concentration of CO_2 and other gases, including water vapor, in the atmosphere increase, more of the earth's radiated heat is trapped. Climate models generally agree that the more CO_2 there is in the atmosphere, the more radiated heat will be absorbed, and the warmer the lower atmosphere will become (other things being equal) (14, 18).

The temperature changes are not expected to be uniform over the earth's surface. If the atmospheric concentration of CO_2 doubles, the average equilibrium surface temperature in the middle latitudies would increase by about $3^{\circ}C$ and as much as 7° to $10^{\circ}C$ at the poles. At the equator, there would be only a very slight increase in temperature. Nearer the poles, a warming trend would reinforce itself (a positive feedback effect). Higher temperatures reduce the highly reflective snow cover so that visible light is absorbed rather than being reflected from the earth by the snow cover. The warmer earth then radiates still more infrared radiation, which is trapped by atmospheric CO_2 (14, 18).

Two significant climatic effects will be produced by these temperature changes. When the temperature difference between equator and poles is reduced, the patterns of general thermal circulation will be altered. In addition, reduced kinetic energy of the atmosphere reduces the wind stress on the oceans, thereby altering ocean thermal circulation patterns (14). Several effects would occur, the most significant of which would probably be major changes in the average temperatures of some coastal areas.

The temperature increases that might already be expected from the CO_2 buildup since 1850 are slightly smaller than the naturally occurring fluctuations of temperature and may thus be lost in the "noise." If the climate models are correct, detection of warming may not be directly detectable until about 2000 (25). Nevertheless, efforts are being taken to apply sophisticated techniques to detect the warming attributable due to today's CO_2 levels, even in the presence of the large amounts of thermal "noise" due to natural temperature fluctuations. One recent study, relying on the apparent correlation between the ratio of sunspot umbra/penumbra areas and northern hemisphere temperature, concluded that there may in fact have been a warming due to CO_2 by as much as 0.4°C during the period 1880-1970 (30). This increase is consistent with a rise in temperature of about $3^{o}C$ for a CO_2 doubling -- and that is the figure predicted by the climate models.

The presence of clouds and dust or particulates makes the net climatic effects caused by increased concentrations of CO_2 more complex. For example, clouds generally reflect more solar radiation away from the earth than the infrared radiation they trap, and thus their net effect is to cool the earth slightly (18). Warmer temperatures may decrease overall cloudiness somewhat. Thus, the less cloudy skies of a warmer earth would probably exert a positive feedback effect, making the earth still a bit warmer (18). Increased particulates from fossil fuel burning might partially block the sun and cause cooling. Some particulates, however, also trap the earth's radiated heat, and their net heating or cooling effect is expected to be small (2).

Virtually all the models agree that the cumulative effects of any known countervailing cooling factors will eventually be less than the warming from CO_2 increases (2, 31). After a careful review of all known countervailing and feedback effects in the climate models, the 1979 National Academy of Sciences Study concluded (14):

> To summarize, we have tried but have been unable to find any overlooked or underestimated physical effects that could reduce the currently estimated global warmings due to a doubling of atmospheric CO_2 to negligible proportions or reverse them altogether.... It appears that the warming will eventually occur, and the associated regional climatic changes so important to the assessment of socioeconomic consequences may well be significant, but unfortunately the latter cannot yet be adequately projected.

B. Why the Temperature Effects are Probably Underestimated

Chem disagrees

Careful assessment of the models suggests that, far from overestimating temperature effects, the models tend to understate the warming that would follow a given increase in atmospheric levels of CO_2. To make model calculations feasible, certain simplifying assumptions must be adopted. The result is that the models do not fully reflect positive feedback effects of climate changes, by which warming of the earth engenders still more warming.

The positive feedback from the melting of snow cover at the poles is one example. Another is the effect of reduced cloud cover. Still another is the effect of increased moisture in the atmosphere. Because water absorbs infrared radiation emitted from the earth even more effectively than CO_2, the increased moisture would tend to increase global temperatures still further.

Another important consideration omitted from the models is the effect of atmospheric trace gases other than CO_2. The realization is growing that gases other than CO_2 produced by man's activities also have a greenhouse effect (12, 32). These gases include nitrous oxide (N_2O), methane (CH_4), ammonia (NH_3), ethene (C_2H_4), sulfur dioxide (SO_2) and the class of chlorofluoromethanes (e.g., CCl_2F_2, CCl_3F). Like CO_2, many of these gases are produced by combustion of fossil fuels. The result is that the warming predicted by the models for various concentration levels of CO_2 is expected to be lower than the probable actual warming, due to what is frequently termed the

Combined Greenhouse Effect (CGE). The correspondence between the ratio of various CO_2 concentrations to preindustrial CO_2 concentrations and the CGE limit is estimated to be as follows:

CO_2 Limit	CGE Limit
1.5	1.3
2.0	1.6
2.5	1.7
3.0	2.2

Thus, for example, the warming associated with a CO_2 doubling (2.0) would be encountered when the CO_2 concentration had reached only 1.6 times the preindustrial level, if trace gases increase as predicted. Since the likely atmospheric growth rates for these gases is quite uncertain, this report focuses on CO_2.

Because these positive feedback effects are not adequately incorporated in the models, estimates of warming from rising CO_2 levels are probably conservative. If the effects of trace gases are added, the warming effects are likely to be still more pronounced.

C. Climatic Effects

Scientific analyses so far have focused on the climatic effects expected from a doubling of atmospheric CO_2 It is important to understand that the magnitude of the effects should continue to increase as the concentration of atmospheric CO_2 grows.

The general types of climate changes expected to result from increased atmospheric concentrations of CO_2 are:

(i) greater evaporation, resulting in more moisture stored in the atmosphere;

(ii) altered rainfall patterns;

(iii) changes in shoreline and inland water levels;

(iv) changes in the growing conditions for plants such as grain crops.

In the Northern Hemisphere, precipitation is generally expected to increase north of 45°N latitude and to decrease south of this line (7). As the atmospheric CO_2 concentration doubles, evaporation would increase generally across the earth's surface, increasing the water content of the atmosphere. As a result, the middle latitudes could receive less rainfall than at present and higher latitudes could receive more. Fertile farm regions in the Midwest and South of the U.S., for example, might warm up, dry out, and become less productive. Dust bowl conditions might threaten agriculture over large areas of North America, Asia, and Northern Africa (2, 10), whereas regions farther poleward might be subject to flooding (7). Similarly, Asian monsoons could be diminished and move northward, significantly affecting agriculture that depends upon the periodic rainfall of the monsoon seasons (7). Past temperature changes of as little as 0.6°C have caused striking geographical changes in precipitation, such as decreased precipitation over much of the USA, Europe, Russia, and Japan and increased rainfall over India and the Middle East (33). Changes caused by recent short-term historical temperature fluctuations are shown in Figure 1.

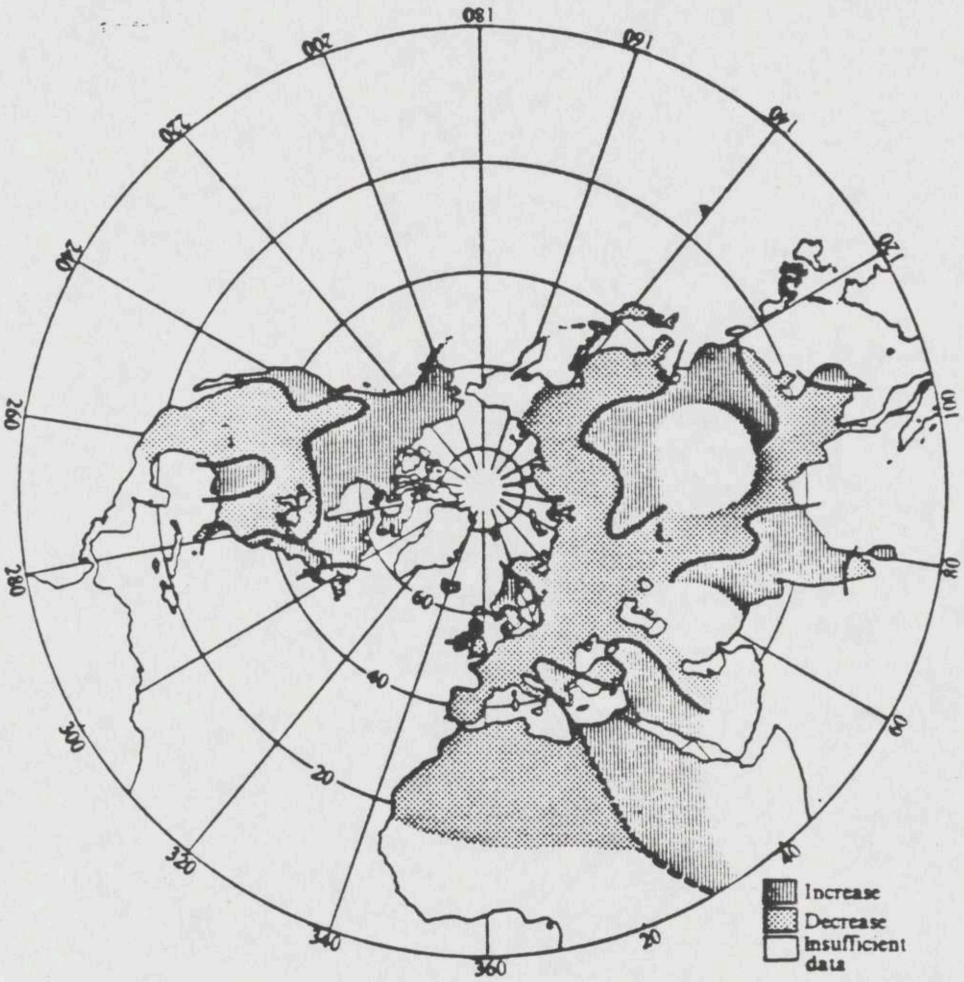

FIGURE 1. Past temperature changes of as little as 0.6° C have caused striking geographical changes in precipitation, such as decreased precipitation over much of the U.S.A., Europe, Russia, and Japan and increased rainfall over India and the Middle East (33).

In lower latitudes a warmer climate and higher rate of evaporation would be expected to lower the water levels of inland lakes and water bodies (2, 10, 11). At the same time, it is probable that the sea level would begin to rise slowly due to melting of polar glacial ice sheets in Greenland and Antarctica (2, 11).

The West Antarctic ice sheet, however, might melt much more rapidly, because it is grounded below sea level by ice shelves where melting might lead to disintegration of the main ice sheet (10, 34). Midsummer temperatures along these ice shelves are now -4^{o}C to -5^{o}C. A doubling of atmospheric CO_2 with its consequent polar temperature rise of 7^{o}C to 10^{o}C, could therefore raise the temperatures along these ice fronts above freezing and destroy them about 50 years after the CO_2 doubling occurred (7). The corresponding rise in sea level of 5 meters following the deglaciation of West Antarctica could have profound effects on the shorelands of the world (7, 10, 11, 18). Figure 2 illustrates the probable effects on the eastern seaboard of the U.S.

With a doubling of CO_2, the entire Arctic Ocean ice pack might eventually disappear in summer, affecting the climate of the whole Arctic basin. Much of the snowcover could vanish and the permafrost could melt, changing profoundly the habitat and ecology of the Arctic (18).

The interrelationships of temperature, precipitation, soil fertility, cloud cover, and other factors are too complex to be accurately modelled at this time. However, weather variations of the past provide clues to the possible

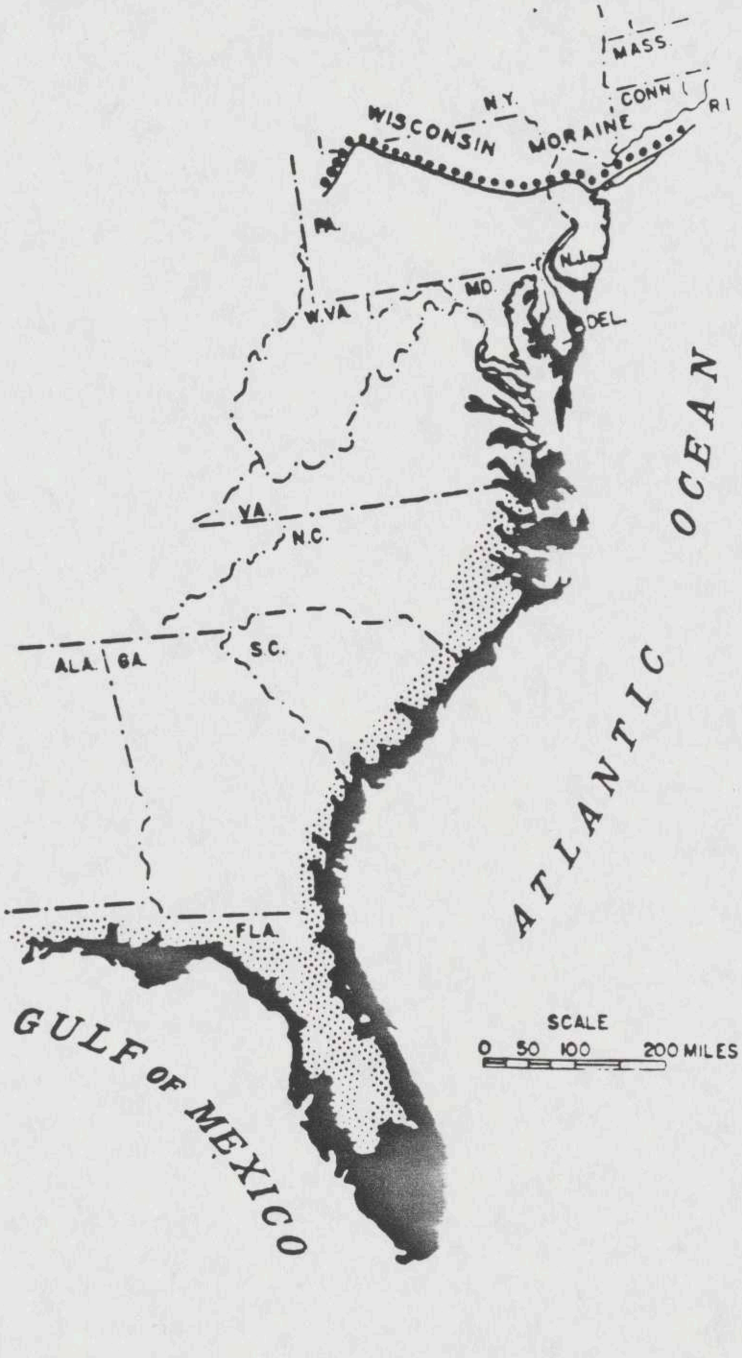

FIGURE 2 Credible shoreline changes which actually occurred during interglacial times when the temperature was a few degrees warmer than at present. The solid area was submerged by a mean sea level rise of about 8 meters. The dotted area was submerged by a mean sea level rise of about 30 meters. (2)

effects on crops of a warmer, drier climate in the middle latitudes.

The responses of agricultural productivity to enhanced CO_2 levels is complex and will depend also on the accompanying changes in rainfall. Careful studies of weather and crop yields in the U.S. from 1901 to 1972 indicate that higher average temperatures depress corn production. Other things being equal, corn production tends to decline about 10 percent for each $1^{\circ}C$ increase in average maximum temperatures over the summer months (12). Warmer and drier conditions are generally unfavorable for corn yields in the U.S. cornbelt; cooler and wetter conditions increase yields. It may be expected that world wheat production would suffer from the drier, warmer conditions that would prevail over the major wheat producing areas of the world with increasing global temperatures. A combined temperature increase of $1^{\circ}C$ and precipitation decrease of 10%, for example, could reduce crops by 20% in major wheat producing areas, such as the USSR (12). One study noted, however, that the effect might be reduced somewhat, or even reversed, by regional increases in rainfall or by enhanced photosynthesis due to higher CO_2 concentrations in the air (19). Rice production would probably rise in the warmer climate, provided that the monsoon rains did not decrease or cause flooding (12).

Agricultural laboratory studies indicate that some agricultural crops might benefit from enhanced CO_2 levels so long as the concentration does not exceed 1000 to 1500 ppm (19). The actual realization of increased production, however, would require that adequate water, nutrients, and human agricultural engineering are also available (35). Whether these conditions would prevail in a world undergoing serious socioeconomic as well as climatic changes is uncertain.

In unmanaged areas, weedy species might flourish at the expense of more desirable ones (9). Many plants grow faster with higher CO_2 concentrations. In a delicate ecosystem in which desirable species are highly stressed, some of them might be eliminated from the system, if forced to compete with species given a greater advantage because of higher CO_2 concentrations (9). For example, natural grasses on which much of the world's grazing depends could be displaced by coarse, unpalatable weeds.

Despite uncertainties about the exact effects on the earth's biosphere of increased concentrations of atmospheric CO_2, it appears that the projected climatic changes could have very significant impacts, mostly unfavorable. In some places the changes might be disastrous. More generally, widespread climate disturbances make it altogether likely that painful social and economic adjustments would be necessary.

D. Socioeconomic Effects

Significant shifts in coastlines, in agricultural patterns, and in water availability could follow the climate changes induced by rising atmospheric concentrations of CO_2 and would affect much of the world's population (2, 11, 16). Certain regions and activities might benefit in some ways from the climate changes. For example, in certain areas, heating requirements for buildings would decline and growing seasons for some crops would be lengthened. Moreover, people would no doubt respond to climate changes by seeking to mitigate the adverse effects and to capitalize on new opportunities. A warmer climate might produce longer growing seasons in some places, but rapid change in a regional climate is likely to produce detrimental effects far in excess of the benefits (11). Most rapid changes produce dislocations that reduce biological fitness and productivity before human or natural readjustments can become effective (2). The prevailing opinion, therefore, appears to be that the social and economic dangers that would result from increased atmospheric concentrations of CO_2 greatly outweigh the potential benefits (2, 11).

Even if the climatic changes resulting from increased atmospheric CO_2 did not lead, in the long term, to net decreases in worldwide food productivity, the short-term transitional effects would be probably severe. Overall agricultural viability depends upon an extensive physical and societal infrastructure, including existing transportation, land use, and land ownership patterns and as well as the availability of water and other resources. This infrastructure might have to be torn down and rebuilt to make a successful transition to a warmer climate (20).

Lower water levels in lakes and streams, changed patterns of rainfall and water availability, and shifts in centers of agricultural productivity could adversely affect the lives of millions of people and the economies of most nations. The altered climate might bring a halt to wheat exports from the United States and other exporting countries, with a consequent drop in GNP and an unfavorable effect on trade balances. In parts of the world where agricultural production is already marginal, even small changes in climate might produce major changes in total productivity and result in famine (10).

Some U.S. scientists are not dismayed by the prospects for agriculture due to changes brought about by increased CO_2 in the atmosphere (19,38). In fact, they believe that any adverse changes can be easily mitigated through agricultural planning and development of appropriate agricultural techniques and crops. This view, however, is limited to consideration of U.S. agriculture and technology and does not extend to world agriculture or unmanaged ecosystems (19, 38).

III. THE DETECTION PROBLEM AND THE IMPLICATIONS OF WAITING

The insidious nature of the CO_2 problem is that if a response is postponed until significant and harmful climate changes are actually observed or until scientific uncertainties are largely resolved, it may be too late to avoid even more severe climate changes. Once the effects of increased CO_2 concentrations are visible enough to arouse concern throughout the world, they may be virtually irreversible for centuries (14, 27).

A. The Detection Problem

There are profound statistical difficulties in detecting the temperature increases and climatic changes that may be caused by increased atmospheric CO_2 concentrations. First, detecting a trend of changing average temperature against the background "noise" of natural temperature fluctuations is difficult. Natural cooling and warming cycles last from several decades to hundreds or even thousands of years (3, 36). The most recent data indicates the world is currently in a gradual cooling trend (37) It will be difficult to detect the human-caused, CO_2-induced warming trend superimposed on a nature-caused cooling trend. In fact, the cyclic cooling phase could mask the CO_2 warming effects until the cyclic cooling phase ends, at which point the normal warming trend would reinforce the CO_2 warming trend and produce a rapid increase in global temperature (37, 41).

Moreover, in the short-term, the earth's average temperature normally varies about a longer-term trend. Temperatures have to be regularly recorded over a considerable time before a definite trend can be detected. Measurements for several years after a trend has reversed are necessary to confirm that the trend has in fact ended. For example, a 20-year average from 1956 to 1975 has been used to give an estimate of the 1965 "signal," (25) that is, the temperature used in determining trends.

To add to the difficulties of detection, the rate at which the oceans absorb heat is not well understood. Particularly uncertain is the rate of heat absorption in intermediate levels of the ocean (from about 100 meters below the surface to about 1000 meters in depth). The National Academy of Sciences study concluded that the capacity of intermediate ocean levels to absorb heat may be significantly underestimated (14)

Because of the ocean's capacity to absorb heat, a temperature rise resulting from increased atmospheric CO_2 concentrations could be delayed, possibly by a decade or two (14, 18). The climatic changes would still occur, but the ocean's 'flywheel effect" would postpone the time when an increase in temperature is detected, much as a large flywheel stores a large amount of energy before it reaches a high speed and is then very difficult to slow down. Meanwhile, time would have been lost, and attempts to counteract the warming trend would be more difficult (14).

B. <u>Implications of Waiting to Detect a CO_2 Warming Trend</u>

Human action to reverse a global warming trend will be extremely difficult and slow. First, there is the great difficulty and long time required to shift the world's fuel use patterns from fossil to non-fossil fuels. Even if the world agreed that CO_2 production must be curtailed to avoid potential disaster, serious difficulties would remain. During the long transition away from fossil fuels, which could cause socio-economic disturbances, the climatic effects of elevated CO_2 concentrations would continue to increase.

Second, if CO_2-induced warming would continue, a massive amount of thermal energy would be stored in the oceans. As the temperature in the atmosphere increases, so does that of the oceans. Once a CO_2-induced warming trend is detected, the great mass of warm ocean will slow the rate at which remedial measures could cool the atmosphere and restore present temperatures. This process of cooling could require many decades or even centuries, in part because cooling could occur most effectively only after atmospheric CO_2 concentrations had decreased significantly. Moreover, as noted above, the rate of absorptive capacity of the intermediate ocean layers is uncertain. If the rate is greater than expected, then more heat will have been stored in the oceans before a CO_2-induced warming trend could be detected. Consequently, the time required for global cooling would be significantly increased.

These two factors suggest that remedial measures begun only after harmful climatic effects are definitely detected may require many decades to take effect and that long lasting changes in world climate may then be inevitable.

IV. ATMOSPHERIC CO_2, TOTAL ENERGY SUPPLY, AND ALTERNATIVE ENERGY FUTURES

Estimating the effects on atmospheric CO_2 concentrations from alternative fuel use scenarios provides a reasonable basis for assessing the relevance of the CO_2 problem to current energy policy decisionmaking. In this report, a conservative model is used to relate global CO_2 concentrations to fossil fuel combustion patterns. That is, based on our best understanding of what produces atmospheric CO_2, the model used underestimates future global concentrations of CO_2.

The basic elements of the model are described below in non-technical terms. Appendix A provides a more detailed, mathematical description of the model.

A. The Model

But what

The model is based on the simplifying assumption that each year a fixed, constant fraction of the total amount of CO_2 in the atmosphere will be taken up by the oceans and the biosphere, which serve as sinks for CO_2. More complex models for estimating global CO_2 concentrations resulting from fossil fuel combustion * lead to the conclusion

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* An average CO_2 emission rate corresponding to that of coal is used throughout the calculations. Coal constitutes approximately 90 percent of remaining worldwide fossil fuel reserves. The CO_2 emission rate for coal is somewhat higher than the present global, average rate for all fossil fuels.

that the oceans' effectiveness as a sink will decrease at higher atmospheric CO_2 levels. Thus, the model used for this report underpredicts the long-term level of atmospheric CO_2 concentration that can be expected to result from burning a given amount of fossil-fuel. However, in the periods through the end of the 21st century, the model used for this report provides predicted atmospheric CO_2 concentration levels that are in good agreement with those produced by more complex models. (See Appendix A).

B. Atmospheric CO_2 Concentrations Resulting From Unrestrained Combustion of Fossil Fuel

Total global coal, oil, and natural gas resources, over 90 percent of which are thought to be coal, are estimated to amount to roughly 300,000 quads.* This is sufficient energy for 1200 years at the present global use rate of 250 quads per year.** For estimating the atmospheric CO_2 concentration resulting from unrestrained combustion of these fossil fuel sources, two energy scenarios are examined. The "high" growth future has fossil fuel energy use growing initially at 4 percent per year, a rate comparable with recent

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* A quad is 10^{15} Btu. One quad per year is equivalent under typical operating conditions to the primary energy requirements of about 20 large (1000 megawatt electric) power plants which could meet the present electrical needs of roughly 10 million Americans; it is also equivalent to the production for one year of about 0.5 million barrels per day of petroleum.

** Continued developments in geophysical exploration can be expected to lead to gradually improved estimates of the resource base, and possibly change the relative percentages of the fossil fuels. But this is not a critical factor in the analysis.

historical growth rates. The "low" growth future has fossil fuel energy use growing initially at 1 percent per year. In both cases, the curve of fossil fuel use is assumed to follow, roughly, a bell shape.* Figure 3 shows the calculated CO_2 concentrations for these two energy futures. Extended to the limit, both cases would result in the use of the entire fossil fuel resourse base.

In the "high" growth future, atmospheric CO_2 levels would be twice the preindustrial level,assumed to be 290 ppm around the year 2025. World fossil fuel use would peak about 2075, and at that time the global CO_2 concentration would be about six times its preindustrial value. Fossil fuel use would decline to negligible levels because of resources constraints about the year 2250. In the "low" growth future, world fossil fuel use would peak about the year 2200 and decline slowly thereafter. Global CO_2 levels would be twice preindustrial levels by 2070 and three times preindustrial levels by 2130.

Compare with Chen

In sum, long before global fossil fuel resources can be completely used, CO_2 concentrations will have risen to levels where, assuming other factors influencing the climate remain unchanged, major climate modification would appear inevitable.

C. Effects on Fossil Fuel Use of Limiting Future Atmospheric CO_2 Concentrations

If the world were to seek to avoid a continued buildup of atmospheric CO_2, the implications for global use of fossil fuels

*More precisely, the fossil fuel use curve is represented as the first derivative of a logistic function.

and for the introduction of non-fossil fuel energy sources are addressed quantitatively below.

First, the curve describing the buildup of CO_2 over the past century can be extended into the future and hypothetically required to level off at a given value, for example, twice the preindustrial atmospheric concentration of CO_2. From this assumed CO_2 buildup curve, the fossil fuel energy that would be burned to achieve the given CO_2 concentration can be estimated. This produces a quantitative relationship between future CO_2 concentrations and allowable levels of fossil fuel use. Then plausible scenarios of world energy demand can be developed so that energy needs from non-fossil fuel sources can be estimated.

Two caveats are important. First, the model is believed to underpredict future CO_2 levels which would result from burning a given quantity of fossil fuels. This results from the simplifying assumptions made to represent an extremely complex physical situation generally involving several coupled equations as a single differential equation. Thus, for a given level of carbon dioxide in the atmosphere, the model allows a somewhat higher fossil fuel burning rate than more elaborate models would yield. Bullshit

Second, there is no <u>unique</u> curve leading to a fixed, long-term atmospheric CO_2 concentration. Many energy futures could all lead to the same CO_2 concentration. Consequently, the results presented below simply indicate the kinds of futures that could evolve. One relationship, however, remains constant -- increases in the growth rate of fossil fuel use, with other sources and sinks of atmospheric CO_2 assumed to be unchanged, lead to corresponding increases in the rate of CO_2 buildup.

Figure 4 presents global energy production curves corresponding to long-term steady-state CO_2 levels of 1.5, 2.0, and 3.0 times preindustrial levels. The figure shows that to achieve a CO_2 steady state of 1.5 times the pre-industrial level, global fossil fuel use would peak in about the year 2000 at a level that is only 15 percent greater than today's value. The annual growth rate of fossil fuel consumption would slowly decline over the next 20 years from an initial growth rate of about one percent in 1980* to 0.7 percent in 1990, and finally to zero at about the turn of the century. Fossil fuel use would then decrease over the next 100 years to a level about two-thirds of today's value.** Baloney

*It is useful to remember that fossil fuel use grew at about 5 percent a year between 1960 and 1973 and about 2 percent a year between 1973 and 1978.

**With the assumptions contained in the model, this level of fossil fuel use could continue indefinitely as atmospheric CO_2 asymptotically approaches 438 ppm. The actual level of CO_2 release would be lower than this and could be better estimated using a more elaborate and realistic model for calculating CO_2

Figure 4 also shows that to limit global CO_2 to an eventual level that is twice the assumed preindustrial value, fossil fuel use would peak in about the year 2030 at a consumption level about two-thirds greater than the present level. The annual growth rate in fossil fuel use would continuously decline from an initial growth rate of about 1.6 percent today to 1.3 percent in the year 2000, to zero in 2030. Eventually, fossil fuel use would approach a limiting value of 220 quads per year, about 88 percent of today's level.

A 200 percent increase in carbon dioxide levels (a tripling) would allow fossil fuel use to increase 170 percent over its 1980 value, peaking in about 2055. The annual growth rate in fossil fuel use would decline from an initial growth rate of 1.8 percent in 1980, to 1.5 percent in 2020, to zero in 2055. In the long term, fossil fuel use would approach a limiting value of about 330 quads per year, about one-third higher than today's level.

The slow and declining growth rates imposed on fossil fuel consumption in these three scenarios should be contrasted with the rapid fossil fuel growth rate experienced over the past several decades. Global fossil fuel use increased by almost 5 percent per year between 1960 and 1973. Between 1973 and 1977, growth occurred at about 2 percent per year, presumably due to the rapid increases in world oil prices. Limiting CO_2 buildup will permit only small and temporary annual increases in fossil fuel use. Rather than growing regularly at between 2 to 5 percent per year, fossil fuel growth would start at maximum values in 1980 of between 0.7 and 1.8 percent per year, depending on the scenario, and decline thereafter for the next several decades.

As emphasized earlier in this report, there are a limitless number of scenarios for burning fossil fuels that could each lead ultimately to the same level of CO_2 in the atmosphere. The three displayed in Figure 4 represent immediate -- beginning in 1980 -- but gradual responses to limiting CO_2 buildup. It is informative to examine the curves which represent allowing fossil growth rates to continue at typically high levels for the next 10 years, until 1990. Figures 5 and 6 show the changed curves for scenarios where CO_2 increases by 50 percent (i.e., 1.5 times preindustrial levels) and 100 percent (a doubling). These calculations alternately assumed that global use of fossil fuels would grow at 2.5 percent per year and 4.0 percent per year between 1980 and 1990. After 1990, consumption would be constrained so that asymptotic CO_2 levels would not exceed 1.5 and 2.0 times preindustrial levels, respectively.

Figure 5 representing a 50 percent increase in CO_2, shows that, with 2.5 percent growth over the next decade, fossil fuel use near the turn of the century would reach a level about 15 percent (about 40 quads) greater than it would if immediate controls were imposed to limit CO_2 buildup. With 4 percent growth over the next decade, fossil fuel use would be about 30 percent higher (almost 100 quads) by the turn of the century. However, there would be a real penalty associated with this near-term rapid growth. With 2.5 percent growth, the time when global fossil fuel use would have to begin declining would move forward about 4 years, from 2002 to 1998. With 4.0 percent growth it would move forward about 7 years, from 2002 to 1995. Moreover, the rate of decline after the time of peaking would be greater with early rapid growth. The average rate of decline subsequently would be 50 percent greater (that is, -0.9 percent rather than -0.6 percent) if fossil fuel use grows over the next decade at 2.5 percent per year, and 100 percent greater (-1.1 percent per year rather than -0.6 percent) if growth occurs at 4.0 percent for the next 10 years.

Figure 6 representing a doubling of CO_2 shows that with a 2.5 percent growth rate over the next decade, fossil fuel consumption would average 10 to 12 percent higher between 1990 and 2020 than if immediate action were taken to limit CO_2 buildup. With 4 percent growth over the next 10 years, fossil consumption would average 25 to 30 percent higher for the same time period. The year when global fossil fuel would have to begin declining would move forward 5 years from about 2030 to 2025 in the case of 2.5 percent growth, and 15 years from about 2030 to 2015 in the case of 4.0 percent growth. The average rate of decline of fossil fuel use after peaking would be about 20 percent greater (that is, -0.8 percent rather than -0.7 percent) if fossil fuels grow over the next decade at 2.5 percent per year, and 60 percent greater (-1.1 percent rather than -0.7 percent) if growth occurs at 4.0 percent over the next 10 years.

Whether the objective is to prevent a 50 percent or a 100 percent increase in atmospheric CO_2 concentration, a continuation of relatively high fossil fuel growth rates for an additional decade (the 1980's) will make the transition away from fossil fuels in the next century more demanding and, given likely economic and institutional commitments, less probable.

Up to this point the discussion has focused on the effects that CO_2 buildup could have on constraining the production and consumption of fossil fuels. To explore the ramifications of these constraints on total world energy supply, it is necessary to examine potential world demand over the same period.

Figure 7 presents two illustrative scenarios of total world energy demand along with the three fossil fuel supply curves from Figure 4. A world high energy demand scenario in Curve A represents a world whose population we have assumed has leveled off at 10 billion people by the year 2100 at an average per capita energy consumption level equal to two-thirds of the present U.S. level. A world low energy demand scenario in Curve B represents a world whose population has leveled off at 8.5 billion people by 2100 at an average per capita level of one-third present U.S. consumption.* Current global energy use per capita is about 20% of the current U.S. level.

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*Curves A and B do not necessarily represent upper or lower limits.

Curve A implies an increase in worldwide energy demand of almost 900 percent by 2100 of which about one-fourth is accounted for by population growth. Curve B represents an increase of about 370 percent, of which about one-half is accounted for by population growth.

The gaps between the curves in Figure 7 describing the use of fossil fuels and the two demand scenarios represent the amounts of non-fossil energy that in each case would have to be supplied to bring supply and demand into balance. Estimates of these required contributions are presented in Table 2. This table shows that to avoid exceeding a 50 percent increase in global CO_2 concentration, and to meet the low demand scenario, non-fossil fuel sources would be required to increase from 26 quads to 125 quads (a factor of five) by the year 2000; or to meet the high demand scenario, to 227 quads (a factor of nine). By 2020, to meet the low demand scenario, non-fossil fuel sources would have to contribute 303 quads, more than is supplied today by all the world's energy systems. To meet the high demand scenario, non-fossil fuel sources would have to supply 588 quads by 2020, more than twice the total commercial energy the world now consumes annually.

The average annual growth rates to achieve these contributions are included in parentheses in Table 1. To limit CO_2 buildup to 50 percent under the low demand future, the non-fossil fuel growth rate would have to average about 8 percent per year between 1980 and 2000, with a doubling time of 9 years. For the following 20 years (2000-2020), the non-fossil fuel growth rate would have to average about 4 percent per year. The respective figures for the high demand future are 11 percent and 5 percent. For comparison, the average annual increase in U.S. electrical generating capacity between 1960 and 1970 was 7.3 percent.

To limit CO_2 buildup to 100 percent (a doubling) under the low demand future, the non-fossil fuel growth rate would have to average about 5 percent per year between 1980 and 2000; for the following 20 years, the non-fossil fuel growth rate would be 4 percent. The respective figures for the high demand future are 10 percent and 5 percent.

In effect, Table 1 summarizes the technical challenges that would be posed in providing new energy supplies if a determination were made to avoid a specific increase in long-term CO_2 levels. The highest growth rates (4 to 11 percent annually) would occur over the next 4 decades. Thereafter, large increments in non-fossil supply would still be needed, though the percentage increases would be much smaller (1 to 3 percent annually).

The principal non-fossil energy sources available to meet these needs are the renewable energy sources (direct and indirect solar), geothermal energy, and nuclear power. The extent to which nuclear power will represent a socially acceptable source of energy is by no means certain at this time. Based on present construction programs and announced reactor starts, it appears that 30 to 50 quads will be provided by nuclear power by the turn of the century.

Of the renewable energy sources, hydroelectricity presently makes the largest, documented worldwide contribution. Biomass very likely also represents a major energy source though the data on its use are poor. The global contribution of hydro power by the turn of the century could range from 35 to 45 quads out of a total potentially developable resource of about 100 quads per year (primary fuel equivalent). Together, then, hydro power and nuclear power could probably displace between 65 and 95 quads by the turn of the century.

The information in Table 2 indicates that if high energy growth and the avoidance of high CO_2 levels (e.g., no more than a 50 percent increase) are jointly pursued, very large contributions to world energy use (between 130 and 160 quads by the year 2000) will be needed from non-hydro renewable sources. With low growth in energy demand, and accepting a doubling of CO_2, very little, if any, additional non-fossil energy might be needed beyond that available from hydro and nuclear emergy by 2000. The possible contributions of these other non-fossil technologies (medium and low temeprature solar collectors; wind turbines, photovoltaic cells, ocean gradient heat engines, power towers; and fuels from biomass*) at any particular time is not certain. The various solar

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* Under certain circumstances, the burning of biomass could contribute to CO_2-induced climate changes. If biomass is burned faster than it can regrow, a net contribution to atmospheric CO_2 would result, just as with the burning of fossil fuels. Similarly, trace combustion gases can contribute to the Combined Greenhouse Effect (see Section II.B).

technologies are in markedly different states of development with some (e.g., solar hot water heating, passive space conditioning, and windpower) already beginning to compete with conventional sources while others are still primarily the focus of research and development.

It is beyond the scope of this paper to determine whether or how non-fossil energy sources could close the gaps depicted in Table 1 between world energy supply and demand. The required analysis would first have to examine projected energy needs over the next half century by each region of the world to determine the kinds and amounts of required energy. Subsequent analysis would then be needed to review the regional availability of non-fossil resources and to determine which sources could provide the most economic and reliable supplies to meet these expected demands.

V. OVERVIEW AND RECOMMENDATIONS

The presence of CO_2 in the atmosphere leads to the trapping of heat radiated by the earth. The higher the atmospheric concentration of CO_2, the more heat that is trapped. Thus, unless offset by other climate-related factors, increased atmospheric concentrations of CO_2 will increase average surface temperatures of the earth. For example, it is estimated that a doubling of CO_2 could increase average surface temperatures by about $3^{\circ}C$ in the middle latitudes and by $7^{\circ}C$ to $10^{\circ}C$ at the poles.

The climatic and socio-economic effects of such a global warming are set out in Section II. Wind direction and speed, ocean currents, and precipitation patterns could be altered. Large and comparatively sudden climate changes could have serious consequences for world agriculture; farming regions might warm up, dry out, and become less productive; dust bowls could be created. These consequences could render capital infrastructures obsolete. The sea level could rise due to melting of polar glacial ice sheets. The resulting coastal inundation could force eventual evacuation of lands now considered to be among the world's most desirable. The Arctic snow might gradually melt, changing profoundly the whole Arctic ecology. While these results are not certain, they are truly grave possibilities to consider. Some regions, however, might experience certain benefits, such as improved agricultural output, as a result of elevated levels of both CO_2 and temperature.

As best as we can now assess them, the possible risks of global climate change appear to outweigh by far any possible benefits. In any case, traditional benefit-cost analysis is ill-suited to problems like this where the uncertainties are so great, the stakes are so high, and the welfare of countless generations who cannot participate in our decisions are involved.

Continued burning of fossil fuels at or near current rates will increase the concentration of CO_2 in the atmosphere. If all remaining fossil fuels were burned over the next one hundred and fifty years,* with consumption following a bell-shaped curve, atmospheric CO_2 levels would double over preindustrial values around 2030, and treble around 2050. The CO_2 concentration would peak near the end of the 21st century at a level perhaps 8 to 10 times that of the preindustrial era. Severe climate modification would be inevitable. As a consequence, unless some unpredicted breakthrough occurs in our understanding or in technology, to avoid major increases of CO_2, fossil fuel burning rates will have to remain at levels far below what would be physically possible to achieve.

The results of the calculations of Section IV suggest that if atmospheric CO_2 concentrations were to be limited to 1.5 times the preindustrial level,** global fossil fuel use would have to peak about the year 2000 at a level only 15 percent greater than today's level. If atmospheric CO_2 were limited to twice the preindustrial level, fossil fuel use could grow through the year 2030, when consumption would decline from a level about 67 percent greater than at present. If more rapid use of fossil fuel were to

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* This assumes that the initial fossil fuel growth rate would be 4 percent, which is close to the long-term historical growth rate for burning fossil fuels.

** This assumes that the buildup follows a logistic curve.

occur over the next decade* and if CO_2 buildup is constrained,** then global fossil fuel use would peak earlier and would begin declining more rapidly.

One implication of these fossil fuel use scenarios is that significant amounts of non-fossil fuel energy will be needed. The amount needed varies greatly, however, depending on the level to which atmospheric CO_2 is allowed to rise and on world energy demand. Energy conservation efforts will obviously be a major factor in determining future energy demand. Assuming that hydro and nuclear power displace from 65 to 95 quads of energy in 2000, that CO_2 buildup is limited to a 50 percent increase over preindustrial values, and that world energy demand is relatively high, from 130 to 160 quads of non-hydro renewable energy would be needed by the year 2000. If world energy demand were relatively low, then from 30 to 60 quads of non-hydro renewable energy would be needed.

In light of these findings, several recommendations are appropriate.

First, the issue has arisen whether the CO_2 problem should be considered today as a major factor in developing energy policies in the U.S. and abroad. For a number of reasons, it should. The analyses of this report indicate that the CO_2 problem cannot

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* For example, if growth occurs at the long-term historical rate of 4 percent, or even at 2.5 percent which is close to the prevailing rate between 1973 and 1978.

** For example, if buildup is constrained to a 50 percent or 100 percent increase over preindustrial levels.

be safely isolated from current debate on energy strategy. Based on our present understanding, if we hope to hold atmospheric CO_2 to 1.5 or even 2.0 times the preindustrial level, planning and then action on an unprecedented global scale must begin now. Unfortunately, it seems reasonably clear that the scientific uncertainties associated with the CO_2 problem will not be resolved in the near future. An even longer period may be required to confirm that observed climate changes are due to increased levels of atmospheric CO_2 rather than the result of normal climate fluctuations. By then the world could be committed to an energy future in which fossil fuel combustion would play an ever increasing role. Both institutional and economic forces would make this commitment hard to reverse, even if climatic changes make reversal appear necessary.

NO

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Second, a priority effort should be initiated within the Executive Branch to consider the implications of the CO_2 problem on energy policy and planning. This effort should develop and examine alternative energy futures in greater depth and with more regional analysis than has been possible in this report. It should also accelerate examination of environmental, economic, and social implications of alternative energy scenarios that involve reducing the use of fossil fuels. Early consideration should be given to the analysis of alternative international mechanisms and approaches to controlling CO_2 buildup, and of alternative fossil fuel energy mixes, including mixes with more natural gas, which emits less CO_2 per unit of energy than other fossil fuels.

Among the issues to be addressed in this priority effort, one question is of particular importance: based on the best current information and analyses, what level of atmospheric CO_2 concentration should be considered as a prudent upper bound?

Clearly, from a perspective of risk to climate and considering the many important values associated with it, the preferred goal would be to limit atmospheric CO_2 buildup to no more than a fifty percent increase over the preindustrial level. To achieve this goal, substantial international agreement and cooperation would be essential, and vigorous actions would need to be taken quickly to control use of fossil fuel.

Holding atmospheric CO_2 concentration to twice the preindustrial level is also a challenging goal, but, on socio-economic grounds, a more manageable one. However, based on our understanding of the climate effects of atmospheric CO_2, a doubling of CO_2 would pose grave environmental threats which we consider unacceptable.

A third recommendation stemming from the analyses of this report is that maximum attention be given to increasing energy conservation and the use of solar and other renewable energy sources both in the U.S. and abroad.*

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* We are hesitant to recommend accelerated reliance on nuclear energy, even though it is not a direct source of CO_2 emissions. Twenty years after its commercial introduction, the future of nuclear energy is still clouded by uncertain but potentially large risks from major accidents, the proliferation of nuclear weapons, and inadequate containment of nuclear wastes.

the long lead times necessary to introduce new energy sources, these contributions can be realized only through a well-conceived, aggressive program whose planning and implementation should begin immediately.

Over the last few years the U.S. has taken a series of important actions aimed at accelerating the introduction of energy conservation and renewable energy technologies. In June 1979, in the nation's first Presidential message to Congress on solar energy, President Carter called for a combined effort to achieve a national goal of meeting 20 percent of our energy needs with solar and renewable resources by the end of the century. Increased energy efficiency is being promoted through taking actions to price energy at its replacement cost, such as decontrolling oil and natural gas prices, through the establishment of a federal conservation bank, through a program of residential and industrial conservation tax credits, through grants to schools and hospitals, and through an expanded program of conservation audits for residential and commerical buildings. Many studies have documented that national energy productivity can be significantly increased, thereby reducing energy growth, while sustaining a growing economy. One recent study estimated that conservation policies over the next two decades could lower energy demand in the year 2000 from a value of 116 quads to 90 quads (a 22 percent reduction) with a loss in GNP in the year 2000 of only 4 percent. Despite this small loss, GNP would almost double between 1977 and 2000.

In the United States and in other developed countries, reducing CO_2 emissions through improved energy efficiency is the most economical way to protect against CO_2-induced climate changes. In fact, over a certain range, this policy does not entail a cost but rather pays a dividend. Cost-effective energy conservation opportunities are abundant and should be the highest priority in the development of global energy policy. Moreover, energy conservation investments beyond the point of purely private profitability are appropriate when external or unpriced factors are introduced, such as long-term risks to national security and to the global climate.

Increasing global energy productivity is the most promising single means of limiting demand for fossil fuels while providing the energy needed for economic expansion. While sustaining economic growth, we could move from a higher energy demand, such as Curve A of Section IV, toward a lower energy demand, such as Curve B, by increasing energy efficiency. Then, it would be easier to meet energy needs from non-fossil fuels, because total world energy demand would be relatively lower, and the gap to be filled by non-fossil fuels would be less.

Equally great is the need to accelerate the worldwide use of renewable energy sources. If carbon dioxide levels are to be held below a 50 percent increase, non-hydro solar technologies such as wind turbines, active and passive space and water heating, and solar cells will have to begin making major contributions to the world's economy by the turn of the present century. Recognizing

The fourth recommendation of this report is that a broad international cooperative effort should be undertaken soon to address CO_2 issues. International collaboration could be particularly helpful in defining the most important issues which would be faced by the developing nations, which comprise about 70 percent of the world's nation-states and people, but account for only about 20 percent of the world's total commerical energy consumption. Over the coming decades, the developing countries are likely to increase significantly their use of energy and become the fastest growing sector in the world's energy economy. If high levels of energy efficiency and reliance on renewables can be incorporated into the economic growth of these countries, an important part of a global strategy for controlling CO_2 will be advanced. U.S. and international assistance efforts should be consistent with these policies. The Agency for International Development, the World Bank, and the International Energy Agency should be aware of CO_2 considerations as they assist developing countries in their planning and development.

In responding to the global nature of the CO_2 problem, the U.S. should consider its responsibility to demonstrate a commitment to reducing the risks of inadvertent global climate modification. Because it is the largest single consumer of energy in the world, it is appropriate for the U.S. to exercise leadership in addressing the CO_2 problem.

One purpose of this report is to set out as clearly as possible the implications of alternative fossil fuel use patterns on atmospheric

CO_2 concentrations. The basic conclusions warrant emphasis. Based on the scenarios described in Section IV, whether the objective is to prevent a 50 percent or a 100 percent increase in atmospheric CO_2 levels, fossil fuel use would have to peak sometime between 2000 and 2030. The challenge is great, but the good news is that we have sufficient knowledge, time, and resources to avoid significant modification of the world's climate -- if we choose to do so.

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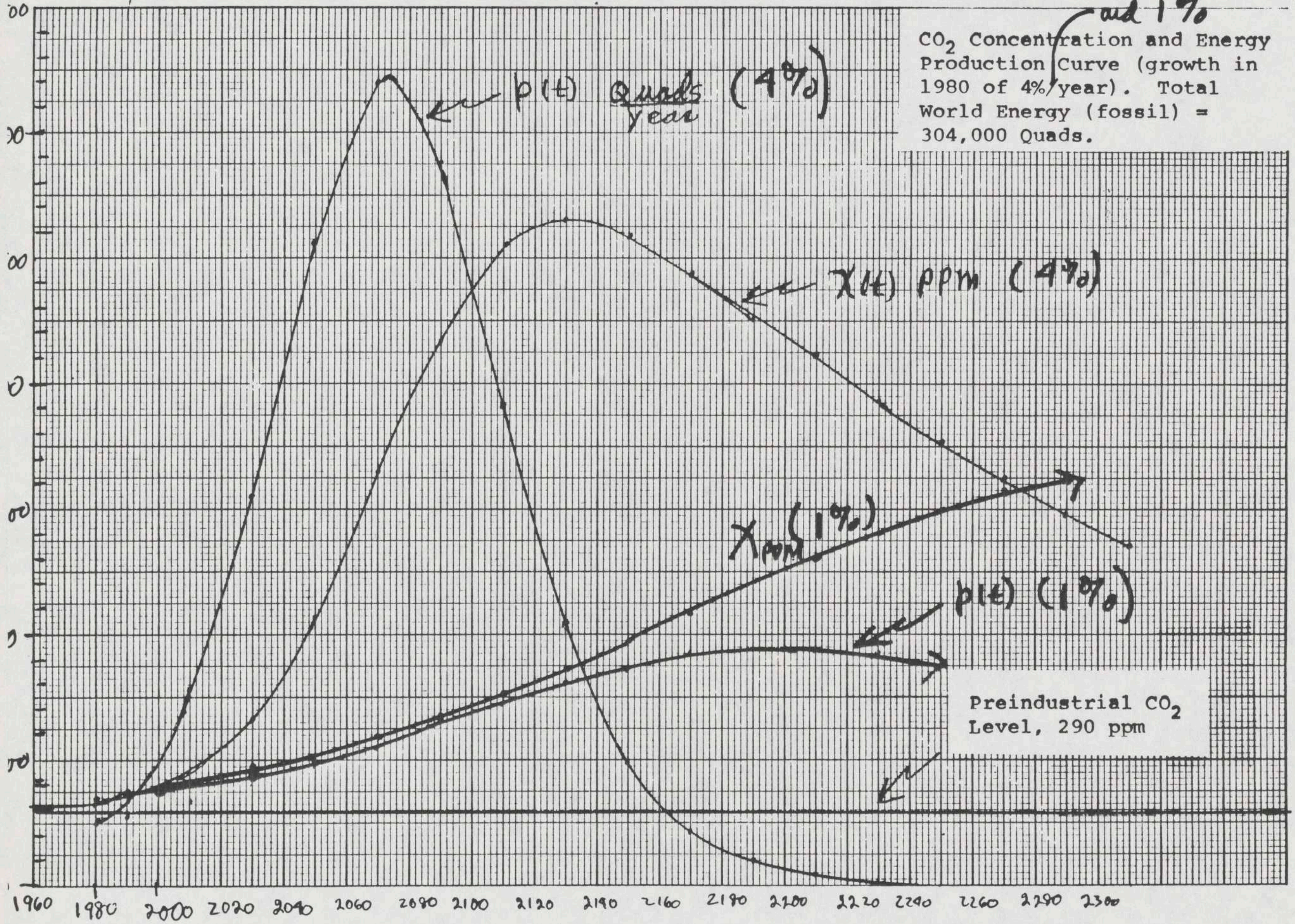
Figure 3.

CO_2 Concentration and Energy Production Curve (growth in 1980 of 4%/year). Total World Energy (fossil) = 304,000 Quads.



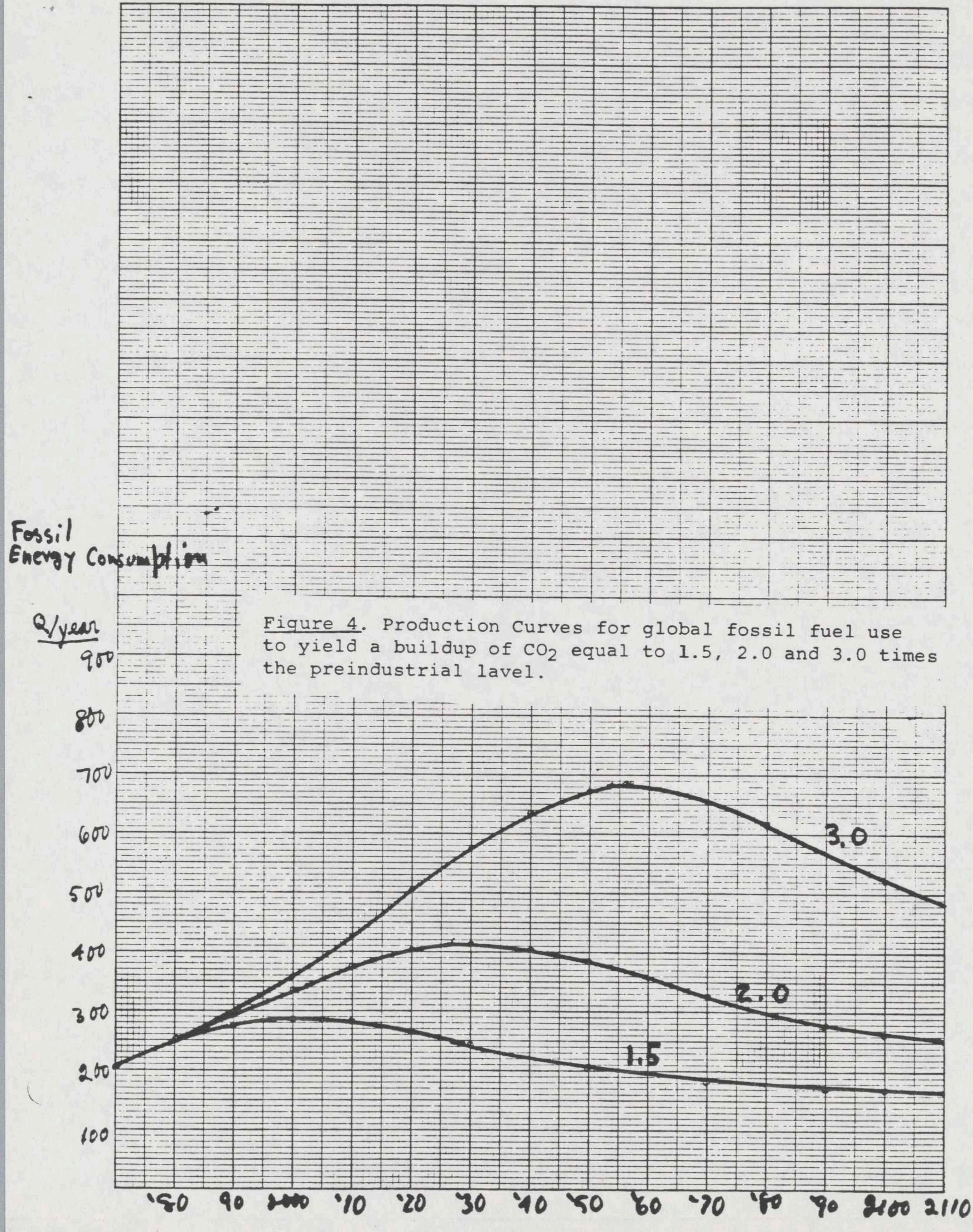


Figure 4. Production Curves for global fossil fuel use to yield a buildup of CO_2 equal to 1.5, 2.0 and 3.0 times the preindustrial lavel.

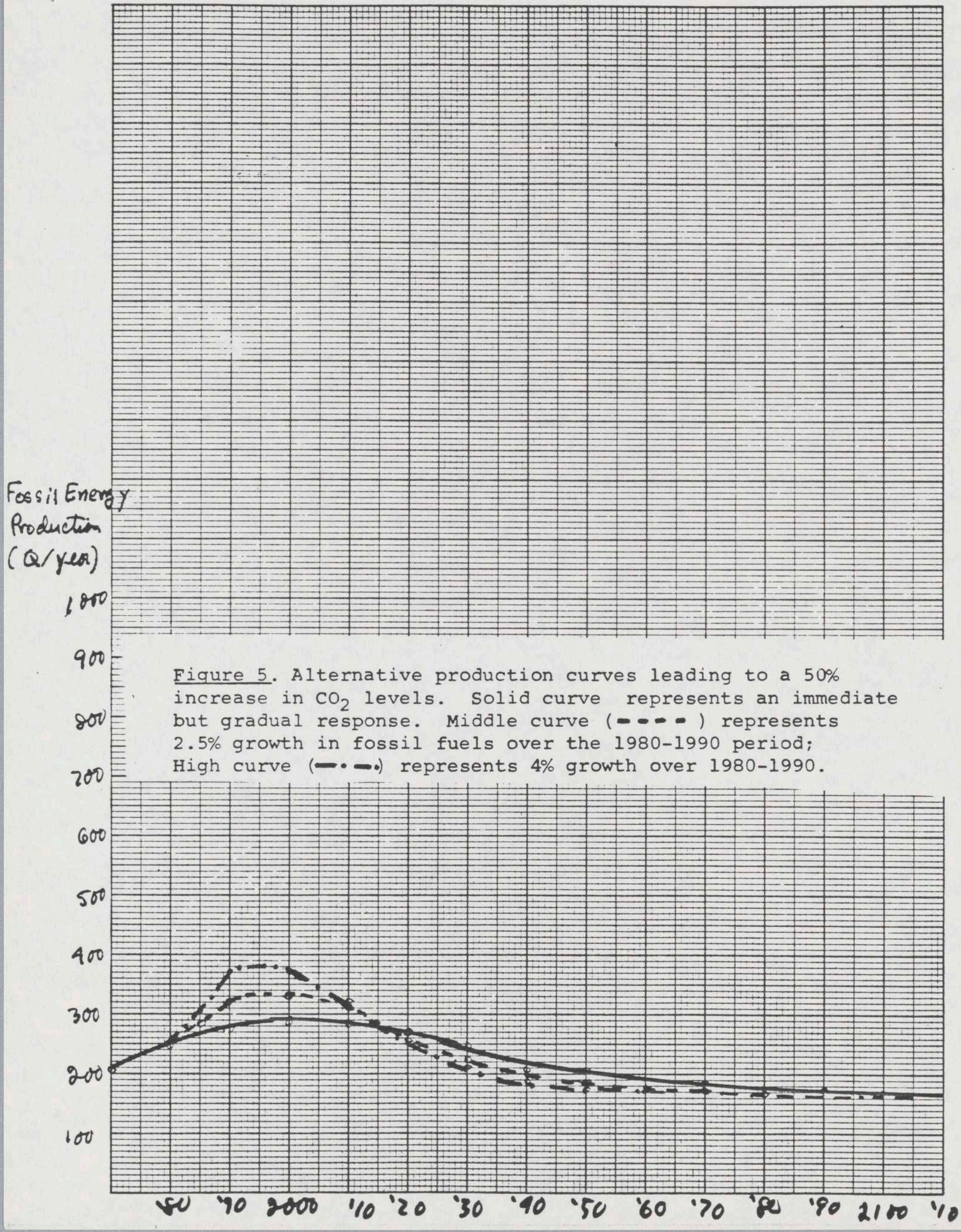


Figure 5. Alternative production curves leading to a 50% increase in CO_2 levels. Solid curve represents an immediate but gradual response. Middle curve (- - - -) represents 2.5% growth in fossil fuels over the 1980-1990 period; High curve (—·—·) represents 4% growth over 1980-1990.

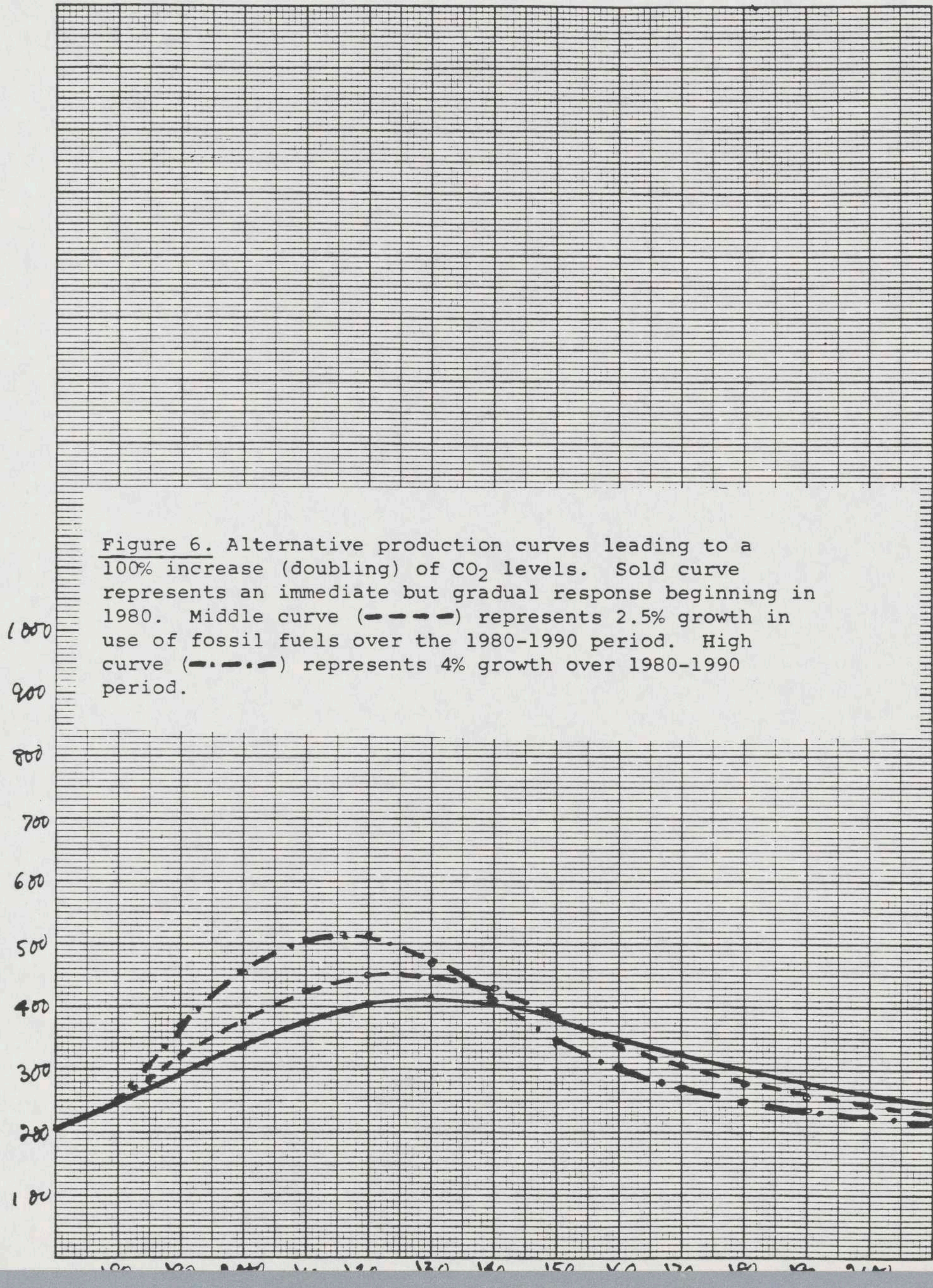


Figure 6. Alternative production curves leading to a 100% increase (doubling) of CO_2 levels. Sold curve represents an immediate but gradual response beginning in 1980. Middle curve (▬ ▬ ▬ ▬) represents 2.5% growth in use of fossil fuels over the 1980-1990 period. High curve (▬ · ▬ · ▬) represents 4% growth over 1980-1990 period.

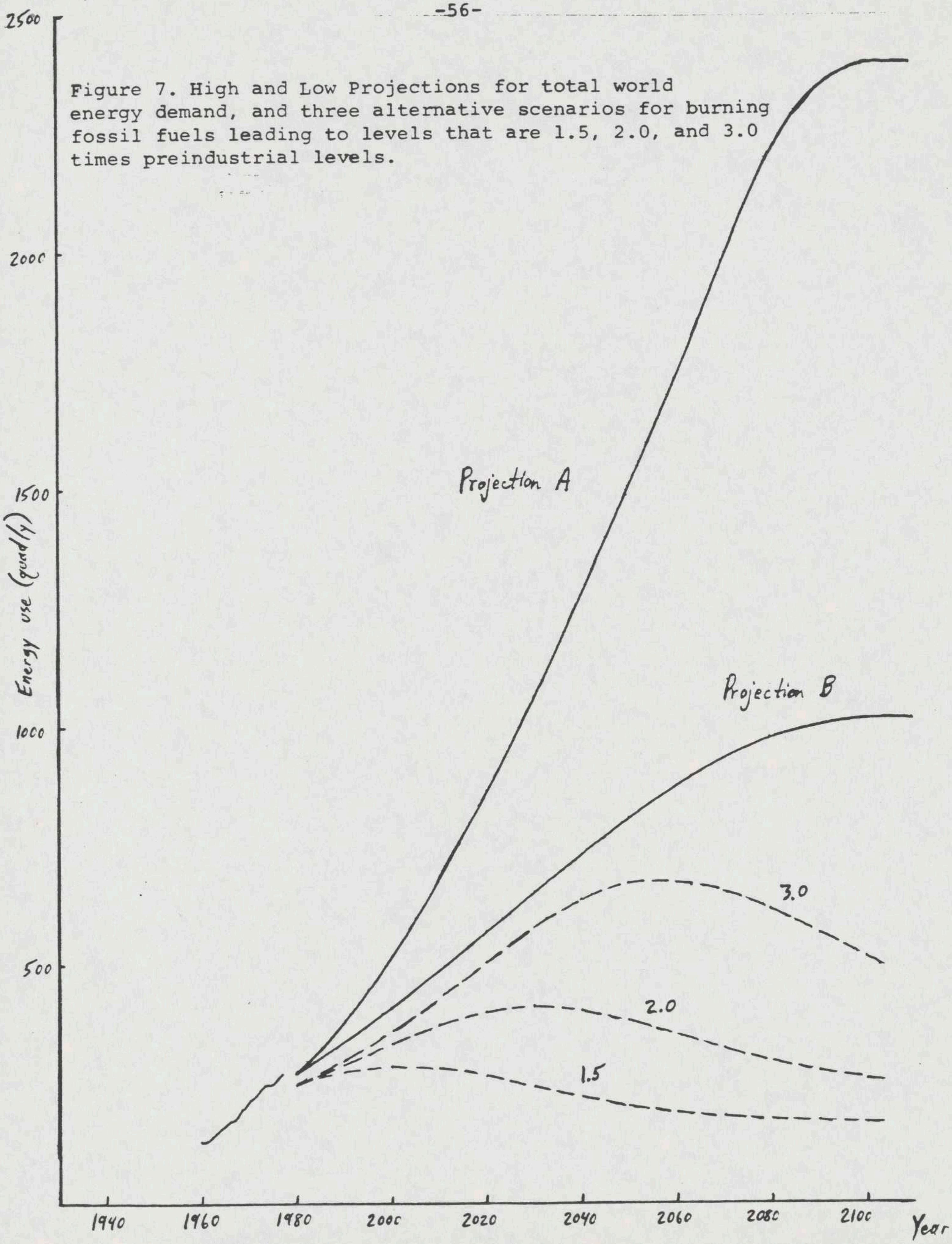


Figure 7. High and Low Projections for total world energy demand, and three alternative scenarios for burning fossil fuels leading to levels that are 1.5, 2.0, and 3.0 times preindustrial levels.
2500
2000
1500
1000
500
Energy use (quad/y)
Projection A
Projection B
3.0
2.0
1.5
1940
1960
1980
2000
2020
2040
2060
2080
2100
Year

Table 1. Projections of non-fossil energy use.

Year	Projection	Required non-fossil energy supply (in quads per year) and (average annual growth rate), assuming a CO_2 ceiling of:*		
		1.5	2.0	3.0
1980	Actual Contribution	26	26	26
2000	High (A)	227 (11%)	178 (10%)	155 (9%)
	Low (B)	125 (8%)	75 (5%)	53 (4%)
2020	High (A)	588 (5%)	452 (5%)	349 (4%)
	Low (B)	303 (4%)	167 (4%)	64 (1%)
2050	High (A)	1283 (3%)	1103 (3%)	816 (3%)
	Low (B)	600 (2%)	420 (3%)	133 (2%)
2080	High (A)	2025 (2%)	1903 (2%)	1584 (2%)
	Low (B)	800 (1%)	678 (2%)	359 (3%)
2100	High (A)	2230 (<1%)	2138 (<1%)	1878 (<1%)
	Low (B)	850 (<1%)	758 (<1%)	498 (2%)

*Expressed as a multiple of preindustrial levels.

APPENDIX A: Mathematical Description of the Model

This appendix summarizes the assumptions and procedures followed in performing the calculations described in Section IV of the report.

Buildup of Carbon Dioxide

Let $M(t)$ be the mass of carbon in the atmosphere (measured in tons) at time t, and M_o the value of M at t=0 (1980). (Mo is approximately 720×10^9 tons). Let p(t) be the worldwide burning rate of fossil fuels, measured in quads per year. At t=0, p = po = 250 quads/years. Let Co be the average emission rate of carbon per quad of fossil fuel burned. (A value of 25 million tons of carbon per quad of fuel was used: this corresponds to the value for coal). Let k be the average fraction of the total mass of carbon in the atmosphere that is removed annually. Then the change in M in a year is given by

$$\Delta M = C_o\, p(t)\, \Delta t - k\, M(t)\, \Delta t \qquad (1)$$

The constant k can be determined by noting that at t=0, ΔM is a known fraction of the input of carbon, $C_o p_o \Delta t$

$$\Delta M_o = \alpha \left[C_o p_o \Delta t \right] = C_o p_o \Delta t - k M_o \Delta t \qquad (2)$$

or

$$k = \frac{(1-\alpha) C_o p_o}{M_o} \qquad (3)$$

Assuming that the biosphere makes no net contribution to the carbon dioxide buildup, about 1/2 of the CO_2 entering the atmosphere each year remains there. Thus we take $\alpha = 1/2$, and

$$k = \frac{1}{2} \times \frac{25 \times 10^6 \times 250}{720 \times 10^9} \cong 0.0044 \, [\text{Year}]^{-1} \tag{4}$$

Equation (1) can be rewritten

$$\left[\frac{d}{dt} + k\right] M(t) = c_0 \, p(t) \tag{5}$$

The concentration of CO_2 in the atmosphere, $\chi(t)$ (in units of parts per million) is related to M(t) by

$$\chi(t) = M(t) \frac{\chi_0}{M_0} \tag{6}$$

where χ_0 is the concentration at t=0, 335 ppm. Thus (5) can be written

$$\left(\frac{d}{dt} + k\right) \chi(t) = c\,p(t) \qquad c = \frac{c_0 \chi_0}{M_0} \tag{7}$$

The solution of (7) is

$$\chi(t) = e^{-kt} \left\{ \chi_0 + c \int_0^t e^{kt'} p(t') \, dt' \right\} \tag{8}$$

Equation 8 was integrated numerically to provide the CO_2 concentrations displayed in Figure 3. The production function, p(t), was taken to be of the form

$$p(t) = \frac{df(t)}{dt}, \quad f(t) = \frac{a}{1 + e^{-\frac{(t-t_0)}{\tau}}} \qquad (9)$$

The constants a, t_0, and τ were determined by setting the integral $\int_0^\infty p(t)\,dt$ equal to remaining fossil fuel resources; by setting po = 250 quads/year, the present value; and by choosing $\frac{dp}{dt}\Big|_{t=0}$ so that the initial growth rate in p(t) is first 1%, and then 4%.

The curves of Figures 4 were calculated by assuming that $\chi(t)$, the solution to Equation 7, is known and follows a logistic function behavior:

$$\chi(t) = \chi_{-\infty} + \frac{\Delta}{1 + e^{-\frac{(t-t_0)}{\tau}}} \qquad (10)$$

where $\chi_{-\infty}$ = 292 ppm. The solution, (10) was then substituted into equation (7) to yield the production function p(t). The three constants Δ, t_0, and τ were determined by requiring that χ equal 335 ppm at t=0, and a preassigned value, $\chi_{+\infty}$, at t = $+\infty$. The third condition was imposed on p(t) by requiring that at t=0, p(0) generated by (7) was equal to 250 quads/year.

Attached are two figures comparing the buildup of CO_2 calculated with the simple model described above with a sophisticated box diffusion model employed by Siegenthaler and Oeschger.* Figure 1 describes the CO_2 buildup assuming that all the world's fossil fuels were burned according to the bell shaped production curve labeled "Input." The agreement between the models is quite reasonable through the 21st century. The subsequent, lower CO_2 levels calculated from the simple model result from the assumed, continued high efficiency of the oceans in removing CO_2.

Figure 2 describes the production rate of CO_2 required to achieve, but not exceed, a 50 percent buildup in CO_2. The agreement between the models is reasonable through the end of the 21st century. Once again, however, the simple model overpredicts the allowed burning rate to achieve the 50 percent CO_2 increase.

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*U. Siegenthaler and H. Oeschger, "Predicting Future Atmospheric Carbon Dioxide Levels," 199 Science 388 (1978); "The Dynamics of the Carbon Cycle as Revealed by Isotope Studies," in Carbon Dioxide, Climate and Society, Proceedings of IIASA workshop cosponsored by WMO, UNEP, and SCOPE, 21-24 February 1978 (J. Williams, editor).

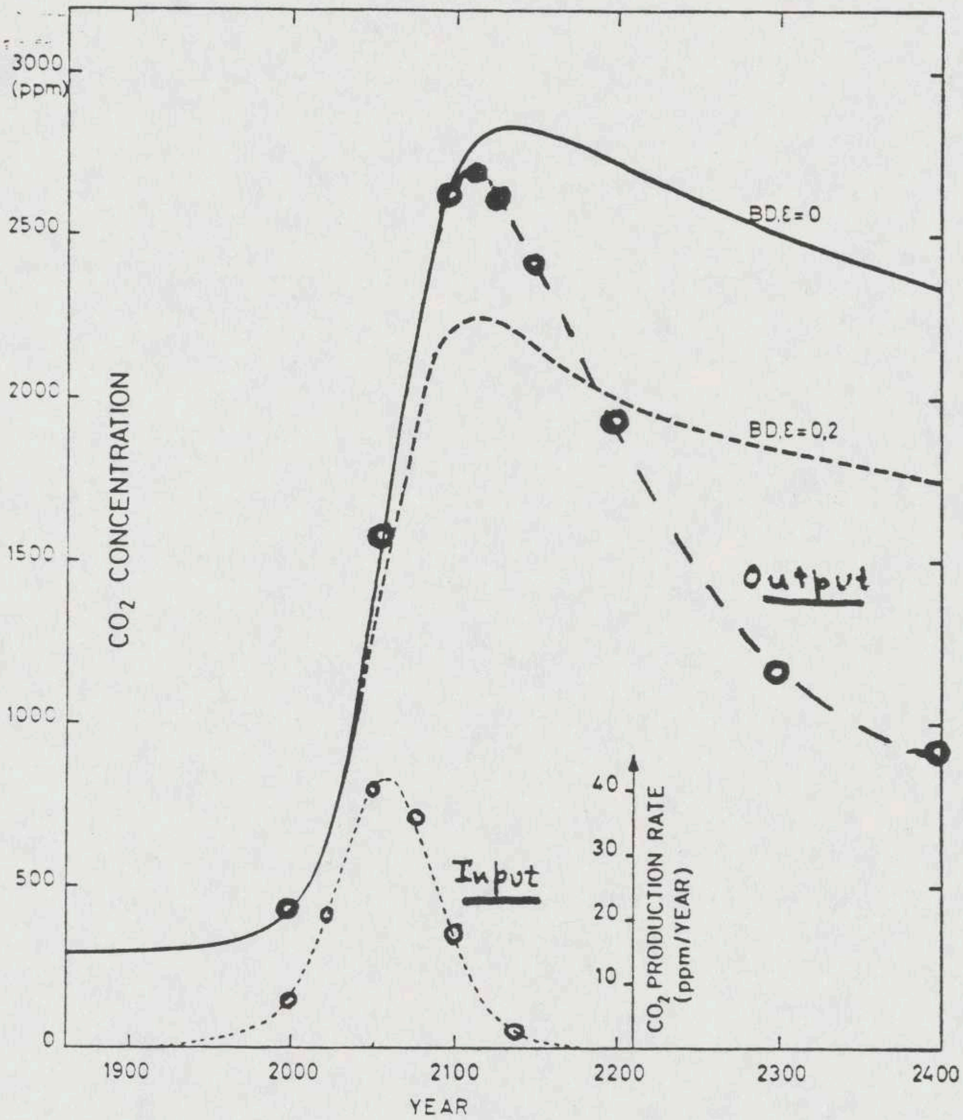

Figure 1. Prediction for the case that all recoverable fossil fuel is burnt. Lowermost curve: assumed CO_2 production rate. The concentration curve for a biota growth factor $\epsilon = 0.2$ is dashed because it would predict a large biota growth that does not seem probable.

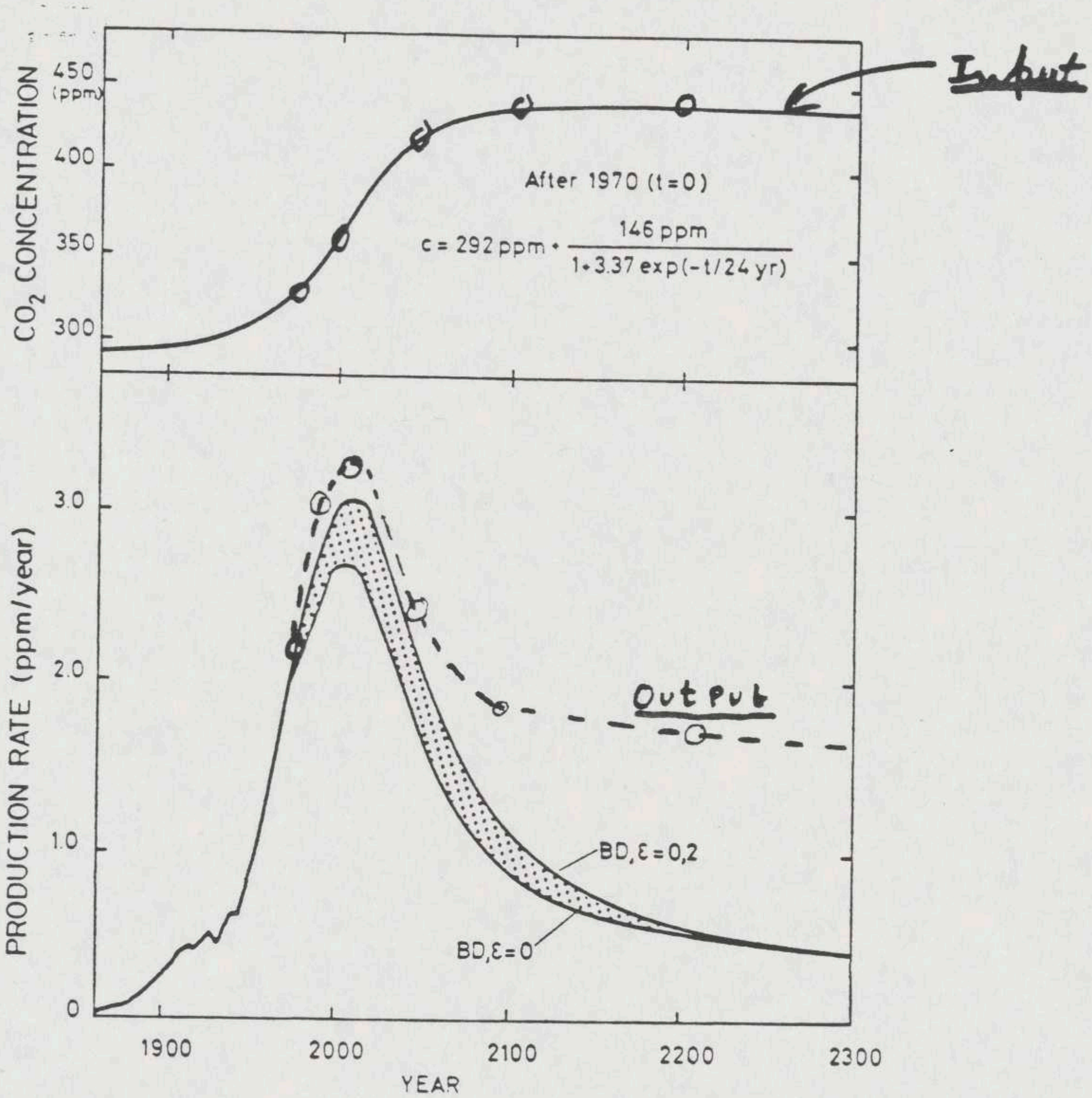

Figure 2 CO_2 production rates, as observed until 1970 and as permitted after 1970, for an increase of the atmospheric excess in a prescribed way (top curve) to a maximum of 50% of the preindustrial atmospheric level.
ϵ = biota growth factor.

Appendix B

Recent Historical Data on Global Energy Use

This Appendix provides a brief description of recent trends in global and domestic energy use.

Table B-1 shows global energy production, 1960-1977, based upon United Nations data. Energy sources other than fossil, hydro, and nuclear are omitted. From 1960 to 1973, fossil energy grew 5.0 percent annually, as did the fossil-hydro-nuclear energy total. During 1973-1977 fossil energy grew 2.1 percent annually while the total grew 2.5 percent annually. These trends are illustrated in Figure B-1. From 1960 to 1977, hydroelectric energy grew about 5.0 percent annually as Figure B-2 shows. The growth rate of nuclear energy production during 1971-1977 is high as shown in Figure B-2.

Table B-2 shows domestic energy consumption, 1966-1979, based upon U.S. Department of Energy data. As Figure B-3 shows, energy consumption declined significantly in 1974 and 1975, then rose at about the 1966-1973 rate, and declined slightly in 1979.

Table B-3 and Figure B-4 show the developing countries' share of world consumption of fossil, hydro and nuclear energy. The definition of "developing countries" in this table includes both communist and non-communist countries. During 1968-1976 the developing countries' share of fossil-hydro-nuclear energy consumption grew about 0.6 percentage points per year.

Table B-1. World Energy Production, 1960-1977

Year	Fossil[a] (quad/y)	Hydro[b] (quad/y)	Nuclear[b] (quad/y)	Total (quad/y)
1960	122.72	7.06	-	129.78
1961	122.22	7.48	.08	129.78
1962	129.25	7.90	.08	137.23
1963	137.45	8.23	.08	145.77
1964	146.08	8.65	.17	154.90
1965	152.91	9.41	.25	162.57
1966	161.53	10.16	.34	172.03
1967	165.96	10.42	.42	176.79
1968	177.30	10.84	.59	188.72
1969	188.10	11.59	.67	200.37
1970	203.00	12.10	.84	215.94
1971	207.90	12.68	1.09	221.68
1972	217.95	13.27	1.51	232.74
1973	230.69	13.52	1.93	246.15
1974	232.57	14.78	2.52	249.87
1975	230.55	15.37	3.53	249.45
1976	243.49	15.04	4.20	262.72
1977	250.54	16.04	5.04	271.63

[a]Original data are in metric tons coal equivalent (mtce). The conversion factor is 28 quads per billion·mtce.

[b]The conversion factor is 84 quads of thermal energy per billion mtce of electrical energy. Hydroelectric and nuclear energy are measured by an estimate of the amount of fossil fuel energy which would be required to generate the amount of electricity provided by these sources.

Sources: These data are based upon United Nations data reprinted in Ruth L. Sivard, World Energy Survey (Leesburg, Va.: Rockefeller Foundation, 1979), pp. 27, 34.

Figure B-1.

World commercial fossil fuel production, 1960-1977.

Source: See Table B-1.

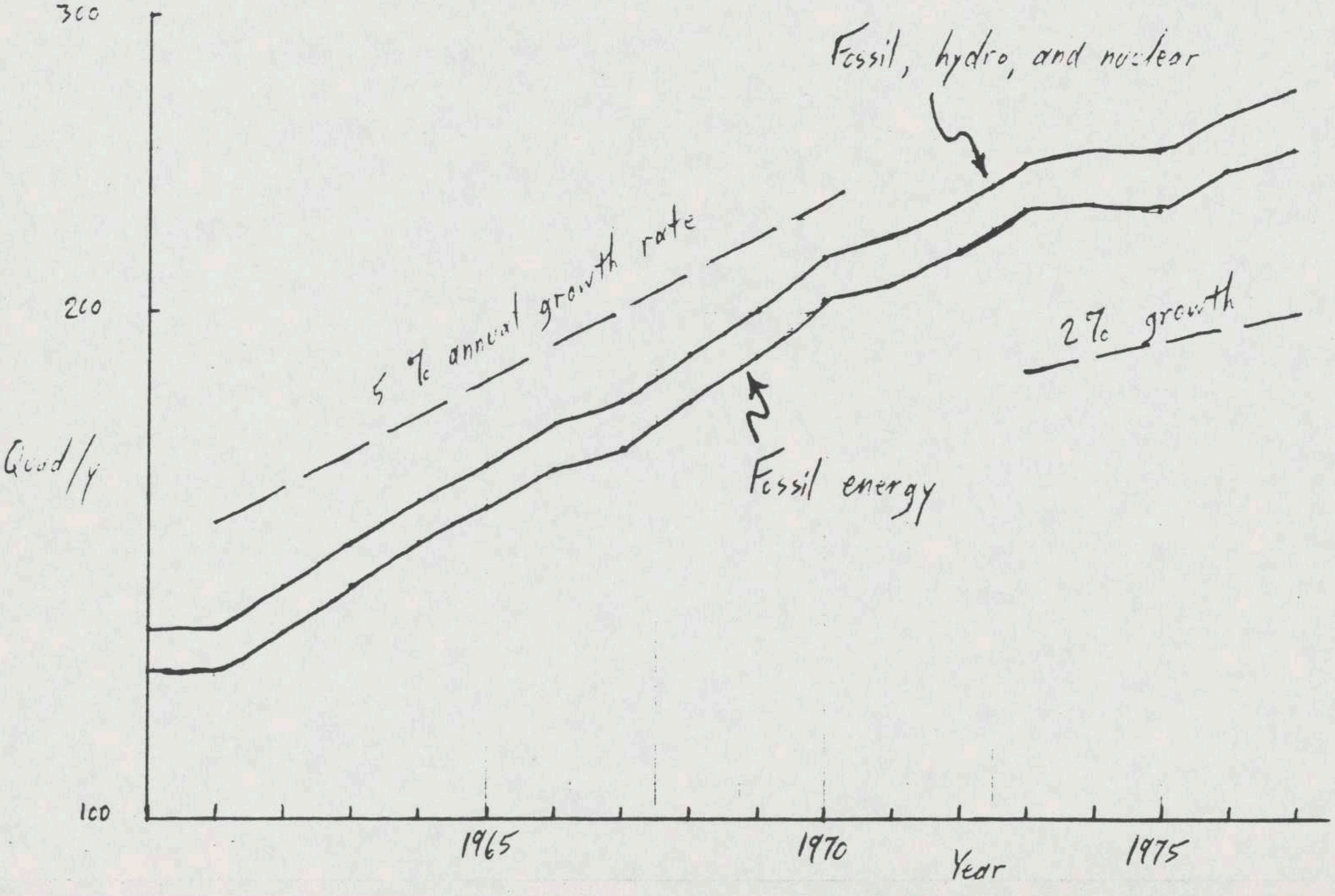

Figure B-2. World hydroelectric and nuclear energy production, 1960-1977. Source: See Table B-1.

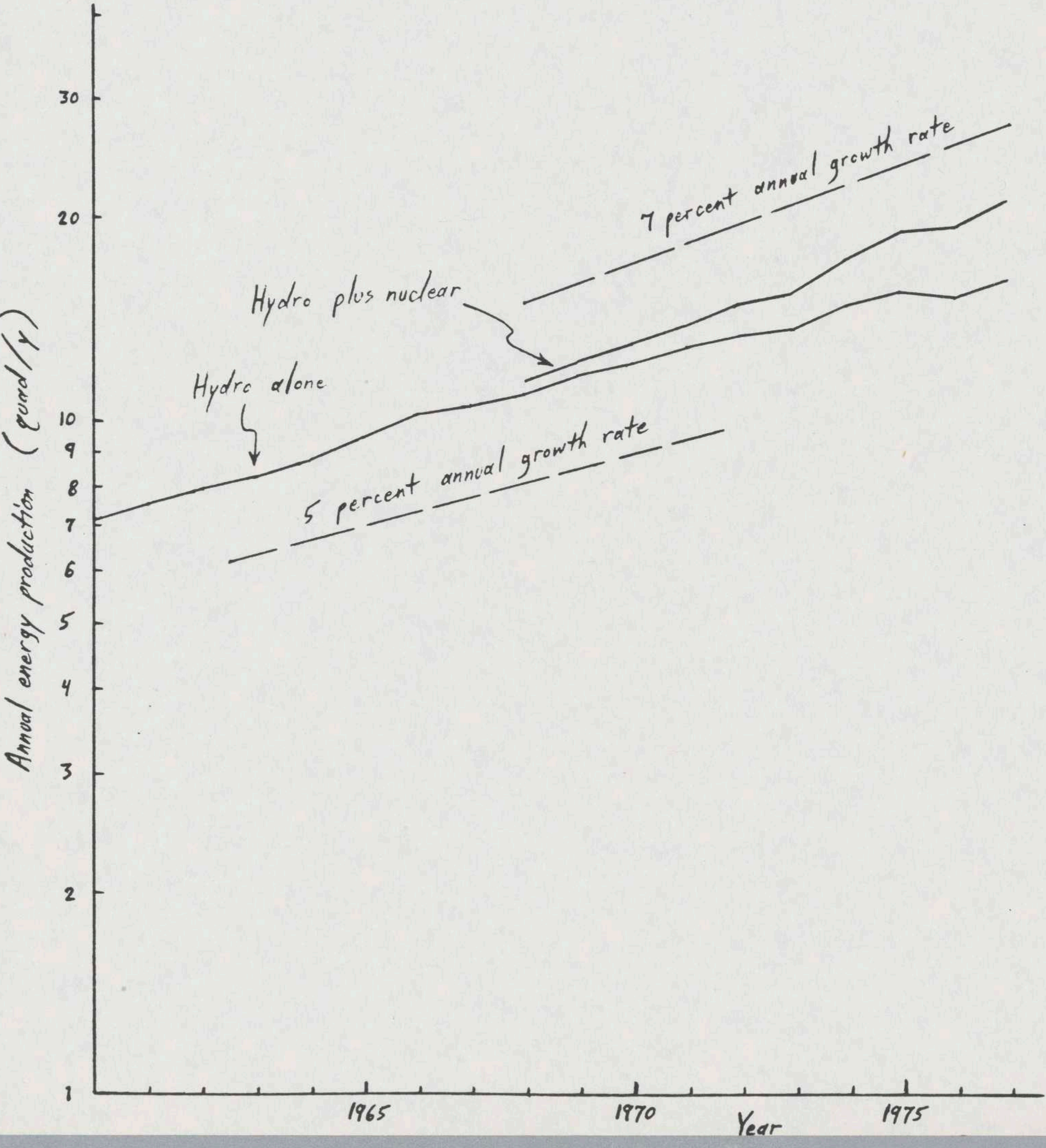

Table B-2. U.S. Annual Energy Consumption

Year	Fossil energy[a] (quad)	Non-fossil energy[b] (quad)	Total (quad)
1966	53.58	2.13	55.72
1967	55.44	2.44	57.88
1968	58.83	2.49	61.32
1969	61.70	2.81	64.51
1970	63.92	2.91	66.82
1971	65.01	3.29	68.30
1972	68.07	3.56	71.63
1973	70.641	3.964	74.605
1974	68.121	4.635	72.756
1975	65.517	5.189	70.706
1976	69.256	5.257	74.513
1977	71.232	5.303	76.536
1978	72.253	6.190	78.442
1979	72.169	6.017	78.187

[a] Includes coal, natural gas (dry), petroleum, and net imports of coal coke.

[b] Includes hydroelectric power, nuclear electric power, geothermal power, and electricity produced from wood and waste.

Source: 1973-79 data are from U.S. Department of Energy, Monthly Energy Review, February 1980, DOE/EIA 0035/02(80), p. 8. 1966-72 data are from DOE's Annual Report to Congress 1978, DOE/EIA-0173/2, Vol. 2, p. 7.

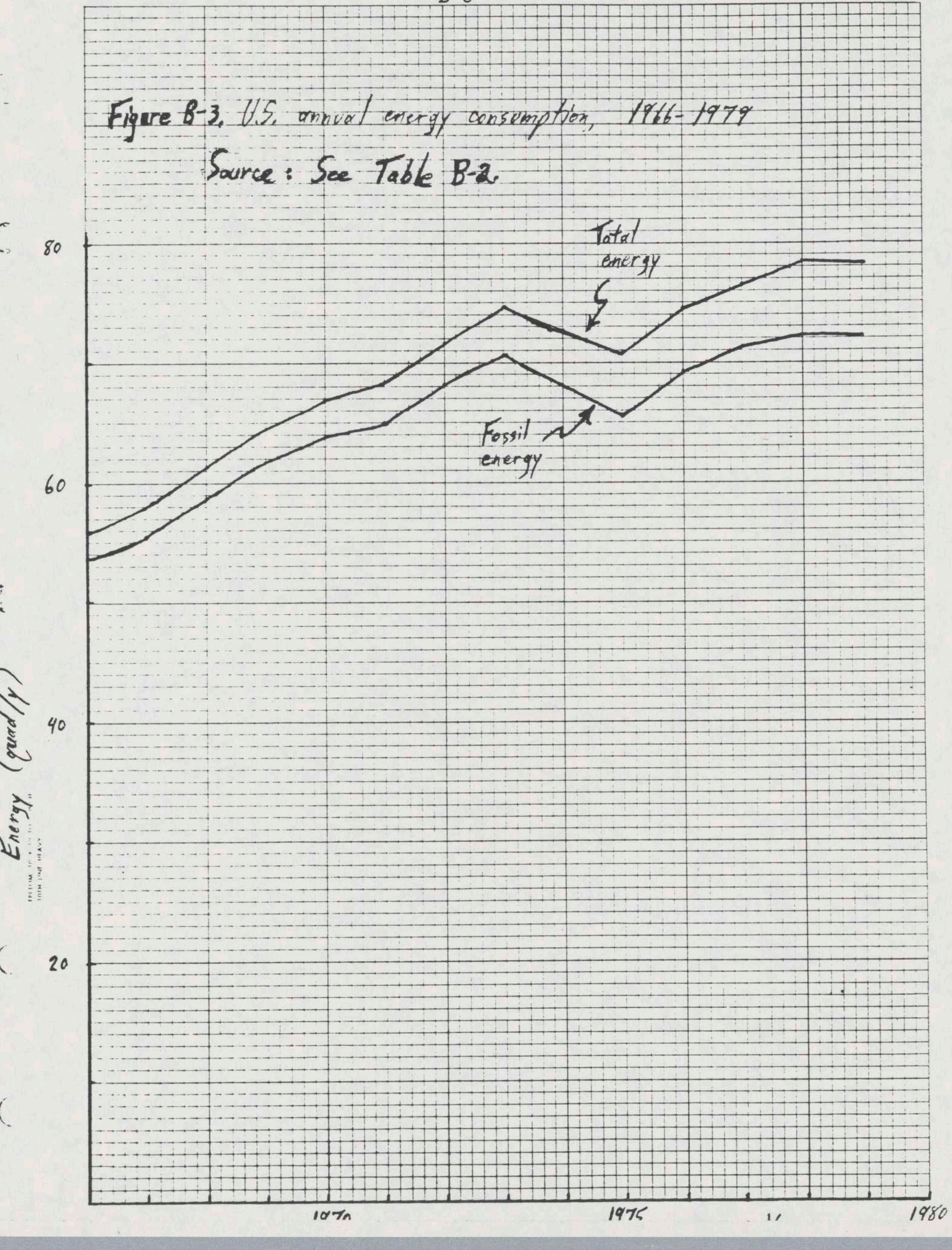

Figure B-3. U.S. annual energy consumption, 1966-1979

Source: See Table B-2.

Table B-3. Developing Countries' Share of Global "Commercial" Energy Consumption, 1960-1976.

Year	Share (%)
1960	19.0
1961	15.8
1962	15.5
1963	15.5
1964	15.8
1965	16.0
1966	16.3
1967	14.7
1968	15.9
1969	16.1
1970	16.6
1971	17.3
1972	17.7
1973	18.4
1974	19.4
1975	20.2
1976	20.6

NOTE: "Developing Countries" include Albania, Greece, Malta, Portugal, Spain, Turkey, Yugoslavia, Fiji, Papua New Guinea, and all of Latin America, Africa, and Asia except Israel and Japan. "Commercial" energy includes fossil, hydroelectric, and nuclear.

Source: Ruth L. Sivard, World Energy Survey (New York: Rockefeller Foundation, 1979), p. 27.

Figure B-4. Developing countries' share of global commercial energy consumption.

1. Bias - CO_2 emissions assume coal

2. ΔT for 2x too high by a third

3. 1974-80 ~ 2% use

4. Manageable problem if 2x OK and
2% is trend.

5 UNCERTAINTY.

Chen p99 CO_2 will double in 2050 with 2%/yr and pes.
never with optimistic.

quite different than CEQ, p30, says
limit doubling requires fossil use at
1.6%/yr 1980-90
1.3% by 2000
0 by 2030

p101 uncertainty, 102 conclusions
p116 Policy Imp.
no way to justify