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Preface

In this volume we are fortunate to have a number of authoritative reviews on subjects of timely interest as well as reports on original work.

Few energy-related subjects can claim our concern to such a degree as CO_2 released by the burning of fuels or the clearing of forests and the consequent climatic modifications this may entail through the well-known "greenhouse effect." In his article "A Current View of Atmospheric CO_2," Ralph M. Rotty presents a carefully weighted and up-to-date description of our present understanding of this highly complex issue. If the climatic changes that follow from increasing concentrations of CO_2 in the atmosphere have only now begun to be evident, the time for responsive action on the part of governments and society in this matter may be well upon us already. In this regard, Rotty's review is highly timely.

While pollution from automobiles may never reach the global proportions inherent in the CO_2 problem, automobile emissions and their control is a serious matter that has already had a profound effect on both the automobile industry worldwide and the industry's customers, automobile owners. "Automobile Pollution Control" by E. L. Resler, Jr. not only gives a thorough review of the complex chemical and physical processes which take place during combustion in automobile engines, but also describes the author's own ingenious research that is aimed at reducing the levels of pollution emitted by internal combustion engines.

Next we encounter a rather different subject, but one having profound consequences as well. The issue raised by DeVerle P. Harris and Donald E. Myers in their article "World Oil Resources: A Statistical Perspective" is just how well we can estimate how much oil remains to be discovered and produced. Only ten years have passed since the world became aware that there was an oil crisis and that such a crisis could be created at will by relatively few actors, but the memory of those anxious years during the 1970s may be fading from our memory. The detailed and scholarly treatment by Harris and Myers serves as a pertinent reminder that world oil supplies will continue to be a paramount issue for the remainder of this century and beyond and, more to the point, that our ignorance about the extent of undiscovered resources may be considerably greater than we might be led to believe by the oil "experts."

Just as the advent of petroleum and its dominance among fuels has emerged as one of the most important features of modern industrialized societies, so is society's increasing reliance on electricity a noteworthy matter. "An Historical Perspective on Electricity and Energy Use" by Peter L. Auer and Warren D. Devine explores the relationship between economic activity and energy use and the apparently uninterrupted trend toward increasing electrification in the United States, a trend that is shared by most industrialized nations. These observations are further amplified by Milton F. Searl in "An Historical Perspective on the Relationship of Electricity to Gross National Product." Although the very large capital expenditures required to expand the capacity of a country's or region's electricity network may prompt some to urge moderation in the future growth of electricity production and use, there seems to be ample historical evidence that economic "progress" and electrification have advanced more or less in step with each other. The authors of these two articles suggest that some important lessons may be drawn from this historical evidence.

Here, as in previous volumes, our interest is to present timely articles by knowledgeable authors in the expectation that these works will serve the interests of professional workers in the field as well as those of serious university students at the graduate or advanced undergraduate level. We welcome future contributions from prospective authors who share these intentions.

PETER AUER

Contents of Previous Volumes

Volume 3

A Current View of Atmospheric CO_2

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I. INTRODUCTION

In the natural biogeochemical processes that take place on our earth, vast amounts of carbon are exchanged among living things, oceans and freshwater, the atmosphere, and components of the solid earth itself. Superimposed on the natural processes are the activities of man. During the nineteenth and twentieth centuries the combination of human population growth and modern technology has resulted in an anthropogenic release of carbon from storage as carbon dioxide. Although the rates of anthropogenic release are still small in relation to the natural exchanges, they are no longer negligible.

Carbon dioxide is not usually regarded as a pollutant in the atmosphere, because it exists there naturally at concentrations in the neighborhood of 0.03%. In fact, carbon dioxide is required in the atmosphere for life to exist. Not only is carbon dioxide necessary in the photosynthesis process, on which all life (directly or indirectly) depends, but atmospheric carbon dioxide also provides a temperature-regulating mechanism that gives our planet a thermal regime suitable for human habitation. Without enough carbon dioxide in the atmosphere, the earth would be ice covered; and with too much, the earth could be uninhabitably hot.

It is this so-called "greenhouse effect" that causes the concern about the concentration of carbon dioxide in the atmosphere. Certain gases, including carbon dioxide and water vapor, are transparent to energy radiated in some wavelengths while absorbing energy radiated in others. Carbon dioxide is relatively transparent to visible light (energy) from the sun, but absorbs energy in the IR (heat) wavelengths of the earth's radiation to space. With or without increased CO_2, the energy leaving the earth must be the same as that received from the sun; with increased CO_2 this requires a change in the thermal structure of the atmosphere—increasing temperatures near the surface and decreasing temperatures at higher altitudes. It is this change in the thermal structure that could result in a profound and long-lasting change in the earth's climate.

This result of increasing atmospheric carbon dioxide suggests that significant changes in precipitation patterns in several critical agricultural areas of the world may take place. The indicated warming near the earth's surface also suggests that some of the high-latitude ice in both hemispheres might melt, and for the cases of glaciers located on land, one result would be the rising of sea levels. Because substantial time is required to melt enough ice to give a significant rise in sea level, this impact may (for now) be of less concern than the impacts that a global climate change could have on food production.

In thinking about the several scientific aspects of this issue, one is led to four broad areas of inquiry.

(a) What are the anthropogenic sources of carbon dioxide? Fossil fuel combustion is not alone as the source of the observed growth of atmospheric carbon dioxide. Conversion of natural forests to agriculture and other commercial ventures has released (still is releasing, in some areas) carbon from long-term storage. Evidence is mounting that during the past century forest conversion contributed to the atmospheric CO_2 increase a total amount of carbon that is of the same magnitude as that from fossil fuels during the same period (World Meteorological Organization, 1981; Houghton *et al.*, 1983; Richards *et al.*, 1983). Fossil fuel combustion has been increasing rapidly for several decades, and the vast amounts of carbon stored in the recoverable reserves suggest that the proportion of the anthropogenic CO_2 coming from fossil fuels will steadily increase.

(b) The fate of all the anthropogenic CO_2 is not clear. The increase in atmospheric CO_2 accounts for only $(2–3) \times 10^{15}$ g carbon of the 5×10^{15} g carbon in the carbon dioxide produced by fossil fuel combustion—the remainder being sequestered in the oceans and in the terrestrial biosphere. If we are to have any predictive capability as to the future carbon dioxide content of the atmosphere, an understanding (including quantitative information) of the fluxes between the several perturbed carbon reservoirs is essential. The time at which CO_2 imposes major impacts on human society depends not only on how fast, and how much, we burn fossil fuel, but also on how much remains in the atmosphere.

(c) Specific changes that are likely to be associated with the general warming near the earth's surface can be only deduced in rather general terms depending upon crucial climatic variables in key geographical areas. Climate modelers have developed procedures that enable them to depict the major features of climate in mathematical terms. These models show clearly that near the earth's surface the atmosphere will be warmed and that this warming will be accentuated in high latitudes, but the magnitude of these changes seems small to the uninitiated. It is the more subtle climatic effects of the new atmospheric circulation pattern resulting from the new temperature regime that are significant.

Length of the growing season is clearly of great importance in agriculture, but it affects natural ecosystems as well. Confidence in our ability to predict the details of such a new climate remains elusive.

(d) How large must a climate change be and of what nature before human welfare is seriously affected? We know that particular combinations of sunshine, precipitation, and temperature are necessary to produce food, but we do not know the limits to which each of these variables can be pushed by developing new varieties of food crops. Frequent intervals like the "dust bowl" could continue to be very serious even with new varieties developed for drier climates. We do not yet know how much the temperature must rise and how long a time is required to give significant melting of polar ice, or how to make good estimates on the full costs associated with such an event. There are many types of potential consequences from a changed climate; evaluation of these is just beginning. Such evaluations must always be made, however, in contrast with the costs to humanity of taking steps now to avoid the climate change.

Each of these areas of inquiry will be addressed below, but a full appreciation of the issues surrounding increases in atmospheric carbon dioxide can only be obtained by recognizing the interdependence between the areas as well as the independent scientific issues of each area. The sources of CO_2 depend on the working of complex systems of human needs—e.g., adapting to a situation of insufficient water supply may be accomplished either by using more energy for irrigation or by importing water; the fluxes from one reservoir to another in the carbon cycle depend on the amount of carbon being partitioned (i.e., the anthropogenic sources) and on the human activity of destroying or augmenting the reservoirs.

In each of the four areas, as well as the feedback mechanisms connecting the areas, vast uncertainties exist regarding both quantitative values and the mechanisms themselves. Before the issue of atmospheric CO_2 can be effectively evaluated and appropriate action can be initiated, at least some of the uncertainties must be resolved. Much research is under way on nearly all aspects of the issue, and it is likely that as some of the uncertainties are reduced it will be found that atmospheric carbon dioxide is neither as serious as has been suggested by some nor as benign as has been believed by others. The truth most likely falls in the middle range: This is an issue that mankind will be able to handle but also one that will require its attention. Thus we cannot afford to be complacent, but rather we must be aggressive and seek a full understanding.

Despite the uncertainties, several aspects are clear. There is growing confidence in the basic conclusion of the National Research Council's 1979 evaluation of the CO_2-induced climate change projected by existing models, the so-called Charney report: "[We have] tried but been unable to find any overlooked or underestimated physical effects that could reduce the currently estimated global warmings due to a doubling of atmospheric carbon dioxide to negligible proportions or reverse them altogether" (National Research Council, 1979). A second review conducted by the National Research Council, at least partially in compliance with the Energy Security Act of 1980, concluded: "The present study has not found any new results that necessitate substantial revision of the conclusions of the Charney report" (National Research Council, 1982). Thus the view that CO_2-induced warming will occur is strong indeed. Questions remain only about how much, with what rate of increase, and with what associated climatic details.

The rate of change is important not only in regard to the climate changes but also to the atmospheric CO_2 concentration itself. Since 1973 the rate of growth of global energy demand has slowed, mostly because of slower growth in the developed world. As a result of increased prices, conservation of energy in a variety of forms has become more commonplace; efforts to substitute other things for fossil fuels has intensified. Consequently, the rate of growth of emission of CO_2 from fossil fuel combustion is no longer continuing at 4.5%/yr (Rotty, 1979), but rather is closer to half that amount (Rotty, 1983). Further, with slowed global population and economic growth the demand for energy in the future is likely to be less than that indicated in earlier projections. Hence accumulation of carbon dioxide in the atmosphere is likely to be slower than was formerly believed, but because of the vast resources of fossil fuel carbon the eventual concentrations are still likely to reach levels sufficient to produce major climate changes.

An additional factor which contributes to the lengthening of the time before the atmospheric concentration of CO_2 reaches a given elevated value is the behavior of other anthropogenic sources. It is now clear that conversion of the world's forests has been a source of CO_2. Combining this source with fossil fuels suggests that a somewhat smaller fraction of the combined anthropogenic source remains airborne. In the future, when the forest conversion contribution has been reduced (because mankind has run out of forests worth converting), the carbon system will then be partitioning only the fossil fuel CO_2 among the oceanic, biospheric, and atmospheric reservoirs. The result of a reduced atmospheric fraction coming from such thinking would be a slowing but not negating of the rate of accumulation of CO_2 in the atmosphere.

These considerations, in spite of the many uncertainties, suggest that we have but a short period of time to increase our understanding of the issue and the possible options before it becomes necessary to take drastic preventative action. However, this time may be *very* short and it must be used to advantage, lest it slip by and action be required in the absence of knowledge and understanding.

Some illumination of these central issues and the uncertainties surrounding the scientific knowledge of each is offered in the following sections.

II. ANTHROPOGENIC SOURCES OF CO_2

Two types of human activity result in major releases of carbon from long-term storage. First, world industrial growth has been fueled largely through the exploitation of fossil fuels mined from the earth's crust. Twentieth century technology has both required and made possible the accelerated combustion of these fuels. Second, population growth has required that increasing amounts of land be used in the direct support of people. This has come at the expense of large areas of the world's natural forests. Much, but not all, of the forest destruction has resulted from the need to increase the amount of cultivated land; the greatest recent pressure in this direction has occurred in the tropics.

A. Fossil Fuel Sources

Evaluation of quantities of CO_2 produced from the use of fossil fuels has usually been based on United Nations energy production data (United Nations, 1978, 1981). Other data sources exist for certain fuels for limited portions of the world which support the United Nations data. Uncertainties in the amount of CO_2 already thrown into the atmosphere result from lack of knowledge of the carbon content of the fuel and inaccuracies in the data on how much of the fuel was actually produced and used.

The total anthropogenic production of CO_2 from fossil fuels and cement has been calculated using methods described by Keeling (1973), Rotty (1973), and (more recently) Marland and Rotty (1983).