THE IMPLICATIONS OF FOSSIL FUEL COMBUSTION ON GLOBAL CLIMATE CHANGE: AN OVERVIEW

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INTRODUCTION

The potential for future global climate change (GCC) and its implications for fossil fuels (FF) currently are hot issues. They are the subject of much ongoing research and scientific debate and they have policy ramifications with international repercussions. The recently completed environmental conference in Rio de Janeiro is a case in point, testifying to the encompassing importance of the topic.

GCC is very complicated and our understanding is far from adequate, hindering our ability to deal effectively with it from either the technical or the policy standpoint. Uncertainties and controversies abound. To highlight the subject for those of us who must deal with it in our daily tasks, the Fuel Chemistry Division of the American Chemical Society is conducting this one-day "pedagogical" symposium. The purpose is not to put forth any specific policy or to advocate any particular scientific position. Rather, it is to provide information on the current state-of-the-science so that as we return to our continuing responsibilities we might be better able to formulate our own decisions regarding both the conduct of our profession and policy alternatives which, as knowledgeable representatives of the scientific and engineering communities, we will be asked to explain and support.

The topic can be divided into two major areas: atmospheric science and fossil fuel implications. This symposium will focus on both. At the conclusion, two papers on policy underpinnings will suggest some techniques that can aid in policy determinations, but policies *per se* are beyond our horizon. We leave them for your personal consideration upon departure this afternoon.

ATMOSPHERIC SCIENCE

There are some things concerning GCC that are well known and beyond serious debate. Among them is the "greenhouse effect" (GHE) which has an unquestioned scientific basis. It is, for example, a major cause of the earth's average surface temperature of 15°C, Mars' -47°C and Venus' 477°C. Figure 1 illustrates the GHE. The GHE and the characteristics of the six principal greenhouse gases will be examined in our first paper.

Essential to our analysis of the present is an understanding of what has happened in the past. One GH gas of great importance to fossil fuel is, of course, CO_2, a major product of combustion. CO_2 enters the globe's carbon cycle which, although generically illustrated on figure 2, is not fully understood. The material balance, for example, cannot be closed. The atmospheric concentration of CO_2 has undergone significant variation over the earth's history and some of those variations have been correlated with climatic changes. Those of the ice ages are an example. Most variations were before man and thus stemmed from natural causes. But over the industrial revolution of the last 150 years, anthropogenic (i.e. man-produced) carbon emissions have caused the atmospheric CO_2 concentration to increase some 25 percent, and this is one basis of the present concern. The world's carbon emissions and resulting atmospheric concentrations of CO_2 over the industrial revolution are shown on figures 3 and 4.

The earth's climate, characterized by such things as temperature, precipitation and soil moisture, has varied considerably over its billion-year history. I show on figure 5 temperature variations over a million-year period. That significant variations have occurred over these long time intervals is not disputed. What has happened over the past 150 years, however, is. Some conclude the earth has warmed perhaps a half degree C during that period; others aren't so sure. Our second paper will address these data of our climatic record.

Large mathematical climate simulations, performed by "General Circulation Models" (GCMs), are essential to both analyze collected raw data and to predict the future. While necessary and useful, they are lacking in several ways. First, present computing hardware and algorithms that solve the huge but necessary multi-dimensional partial differential equation sets are not yet fully up to the task, at least when the cost of calculation is considered. Second, our knowledge of the fundamental processes involved (including complicated and significant climatic feedback mechanisms) is not sufficient even if they were. Third, the data presently available are not complete enough nor understood well enough to enable full validation of our models. Nevertheless, GCMs are a major tool in our armamentarium. Two papers will focus on GCMs, the first on the characteristics of the models, and the second on differences among the computed results (testifying, thereby, to the present state of affairs).

As is now clear, there is a great deal of uncertainty in our present ability to draw causal relationships between the GHE and GCC. Research results are reported almost daily that affect them; a recent example being new data on the role of atmospheric aerosols. Significant scientific controversies remain. These ambiguities are bases for differing policy alternatives as well as food for future research. Wrapping up our morning will be a paper directly focusing on these uncertainties and controversies.

FOSSIL FUEL IMPLICATIONS

The fossil fuels of interest are natural gas, petroleum, and coal. The fuels have different properties that cause them to produce different amounts of CO_2 as one of their combustion products. To release equal amounts of energy from combustion (assuming 100 percent efficiency) and normalized to natural gas, these three fuels create approximately the following ratios of CO_2 (on a weight basis):[5]

Natural gas -- 1.0   Petroleum -- 1.4   Bituminous Coal -- 1.8

The differences are significant enough to make fuel selection an important determinant. But even the lowest, natural gas, creates sufficient CO_2 to itself be a concern. Thus ways of minimizing CO_2 releases from fossil fuel combustion have received considerable attention. In the first of two papers this afternoon, we will learn more details of the fuel's chemical and physical properties and how, through better combustion efficiencies and fuel switching, we can mitigate the problem. The second paper will deal specifically with the post-combustion capture and sequestration of CO_2, a technology presently in its infancy.

POLICY FORMULATION

While this symposium will not address or analyze specific policy proposals, either those already on the table or those lingering in the background, their existence and importance cannot be ignored. Science plays a part in policy formation. In addition to developing better means of climatic prediction and CO_2 control, there are other ways in which science can help. Closing out our symposium will be two papers that suggest ways in which objective analysis can contribute to the elucidation of crucial factors surrounding these policies. The first will deal with a unified economic analytical framework. The second will demonstrate a way in which uncertainties quantitatively can be dealt with in GCMs, significantly reducing the spread of possible outcomes.

Finally, we will round out our day in a panel session with all authors fielding questions from the audience.

SOME OTHER IMPORTANT ASPECTS

There are additional factors that are now and will remain major determinants of future events. As important to an understanding of the issue as the science of GCC and FF combustion *per se*, they include, for example:

- *International differences* as represented by differing aspirations and priorities among the developed and the lesser developed nations.

- *Political differences* as represented by the various positions taken by environmental protectionists and CO_2-producing industries.

-- *Philosophical and moral issues* as represented by population and its control.

We do not have the time to delve into these matters in detail. But do not take their limited mention as an indication of relative influence. It is only time, not importance, that forces us to deal primarily with other things; in the end, these issues may well prove to have the greatest influence of all on the world's response to the threat of GCC from the GHE. It is important that we technologists also appreciate them and I'll finish this overview with a very inadequate coverage of a few of the most important . . .

GH gases are worldwide, and dealing with them will, of necessity, require a coordinated, international approach. But not all nations are involved equally. First, the predicted climate changes vary; some nations may even benefit as the agricultural environment of their country is bettered at the expense of another nation's loss. Second, many of the developing countries are wrestling with horrendous health and economic woes; their priorities are on the present and not on what might (or might not) be done to affect GCC many years hence. Relatively poor and technically primitive, whatever they do will require both technological and economic aid. (I note in passing that the Montreal Protocol on CFC control was first rejected by these countries who joined in only after the developed nations offered economic assistance.) And third is the question of equity these struggling nations raise: "It is the rich nations of the world that have polluted the global nest while achieving their status of well-being; they should pay for it, not us," one hears them exclaim, adding, "The well-off nations should now help us reach equal wealth."

One cannot escape the economic consequences of the moment, as policy discussions in the U.S. reveal. It is no simple matter to suggest the present economic base of this country, which is highly dependent upon fossil fuel combustion, should be quickly altered. At the same time, there are those with a genuine concern for long-term environmental consequences who auger for immediate constraints on CO_2. Feeling we cannot afford the time it will take to obtain a better scientific basis for policy, they believe the downside risk is too large to wait. So even in a single nation, legitimate differences of perspective lead to radically different political positions.

Finally, there are some moral factors that cannot be escaped. One major determinant of the magnitude of future CO_2 emissions will be the number of people generating it -- the world's population, which is rapidly rising. If the trend continues as predicted, it will swamp CO_2 emission controls. That, in turn, suggests population control, a highly emotional and contested factor but nonetheless a very important determinant.

SUMMARY

To illustrate how factors affected by technology and those that are not are interminably intertwined, I use an identity proposed by Gibbons[6] several years ago. One can estimate CO_2 emissions at some time, T, by:

$$\begin{aligned}
\text{CO}_2\text{ Emitted @ time t=T} &= \text{CO}_2\text{ Emitted per Unit of Consumed Energy @ t=T} && (1)\\
&\times \text{ Energy Consumed per Unit of Gross Domestic Product @ t=T} && (2)\\
&\times \text{ Gross Domestic Product (GDP) per person @ t=T} && (3)\\
&\times \text{ Population @ t=T} && (4)
\end{aligned}$$

Letting E represent consumed energy, we rearrange and define four quantities, A, B, C, and D, in the process:

$$\begin{aligned}
\text{CO}_2\text{ Emitted @ Time T} &= A\ \frac{(\text{CO}_2\text{ emitted/E) @ t=T}}{(\text{CO}_2\text{ emitted/E) @ t=0}} \times \frac{\text{CO}_2\text{ emitted @ t=0}}{\text{E @ t=0}}\\
&\times B\ \frac{\text{(E/GDP) @ t=T}}{\text{(E/GDP) @ t=0}} \times \frac{\text{E @ t=0}}{\text{GDP @ t=0}}\\
&\times C\ \frac{\text{(GDP/person) @ t=T}}{\text{(GDP/person) @ t=0}} \times \frac{\text{GDP @ t=0}}{\text{person @ t=0}}\\
&\times D\ \frac{\text{(population @ t=T)}}{\text{(population @ t=0)}} \times \text{population @ t=0}
\end{aligned}$$

The beauty of this representation is that the four quantities on the left are merely ratios of the future ($t = T$) to the present ($t = 0$), while the right-hand quantities contain information only on the present. Further, it separates effects of energy technology (A & B) from other determinants (C & D). "A" reflects emissions from the generation of such useful energy forms as heat, electricity and motion; improving system efficiencies and fuel switching can lower it. "B" measures "energy efficiency" changes -- how we use that energy -- and reflects (among other things) end-use conservation. These first two terms embody just about all that energy technology can do. "C" is a measure of the change in productivity of a people. It goes up with an improved standard of living and the objective is to *increase* this parameter. "D" invokes all kinds of controversial considerations if there is an attempt to control it.

Relative to the present, one can estimate future emissions of CO_2 for a local region, a nation or, indeed, the world by insertion of the proper values for A, B, C, and D. If their product is lower than one, emissions at T are less than those at present; if it is greater than one, they will be more. As we shall see, all four are important and each must be appreciated.

Using available data and predictions of the experts, I have estimated the values of the four quantities, updating similar values computed earlier[7] for the 35-year period ending in the year 2025 for three different regions; the U.S., Africa, and the world. Assuming the percentage of useful energy generated by all fossil fuels remains constant, my predictions of improved efficiencies and fuel switching were optimistic; for example, in the U.S. average overall system efficiency improves some 38%, coal use drops 30% and oil use drops 20% (both replaced by natural gas) over that time. The results were:

	A	B	C	D	AxBxCxD
United States	0.67	0.71	1.74	1.21	1.00
Africa	0.76	1.91	0.73	2.44	2.58
World	0.71	0.74	1.67	1.60	1.40

The implications are clear. Under these high-efficiency, high-gas, low-coal assumptions, CO_2 emissions stay the same only in an advanced-technology nation where population growth is simultaneously limited. They increase elsewhere despite what technology can do. To control worldwide emissions, non-energy technology factors (e.g. productivity, population) also must be dealt with, with significant international and moral implications. It should be noted, however, that without technology providing large reductions in A and B, the situation would be far worse -- technology is doing its part!

Our symposium today focuses only on the first parameter, A, which deals with energy generation by fossil fuel combustion. That in itself will be difficult to do in only a few hours' time. The impacts of the others should not be minimized, however. For they also have a critical importance in matters concerning global climate change.

1. Adapted from Schneider, S. H., *Science* **243**, 772 (1989). Copyrighted by the AAAS; reprinted by permission.

2. *Changing By Degrees: Steps to Reduce Greenhouse Gases*, U.S. Office of Technology Assessment report OTA-O-482, U.S. Government Printing Office, Washington, DC (Feb. 1991).

3. *Trends '90*, Carbon Dioxide Information Analysis Center report ORNL/CDIAC-36 (1990).

4. Intergovernmental Panel on Climate Change, *Climate Change - The IPCC Scientific Assessment*, Cambridge Univ. Press (1990). Copyrighted by the IPCC; reprinted by permission.

5. Garrett, C. W., On Global Climate Change, Carbon Dioxide, and Fossil Fuel Combustion, *Progress in Energy and Combustion Science*, in press.

6. Gibbons, J. H., The Interface of Environmental Science and Policy, in *Energy and the Environment in the 21st Century*, Tester, J. W., Wood, D. O. and Ferrari, N. A., eds.; MIT Press, Cambridge, MA (1991).

7. *Op. Cit.* 5.

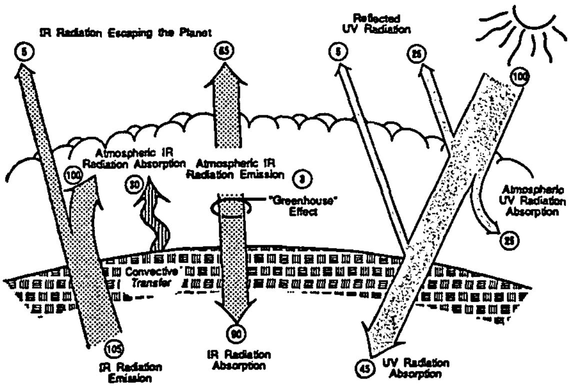

Figure 1

THE GREENHOUSE EFFECT

Source: Ref. 1

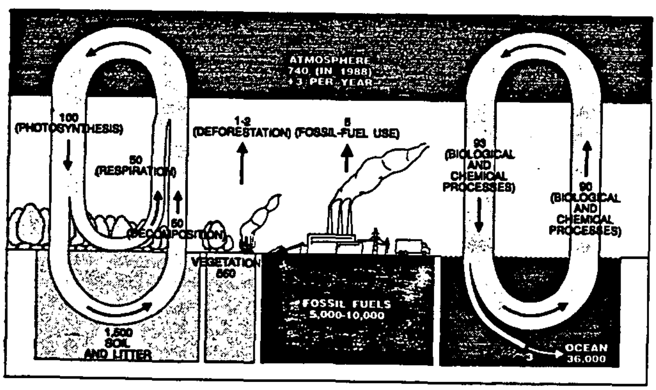

Figure 2

GLOBAL CARBON CYCLE

Source: Ref. 2

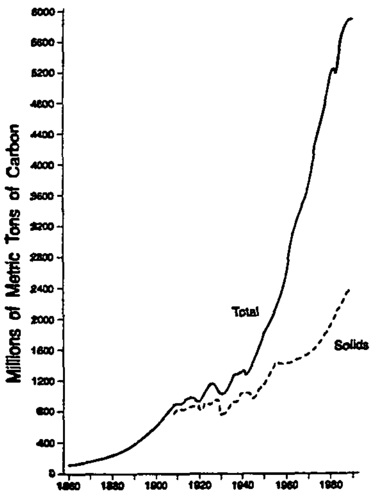

Figure 3

GLOBAL CARBON EMISSIONS

Source: Ref. 3

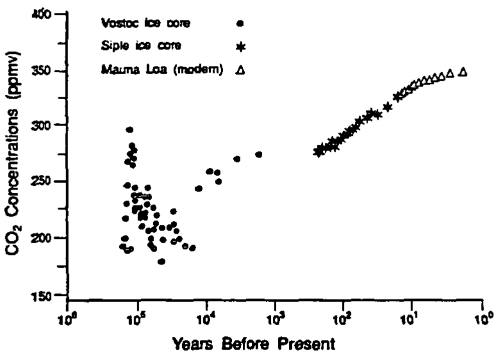

Figure 4

CO_2 ATMOSPHERIC CONCENTRATIONS

Source: Ref. 3

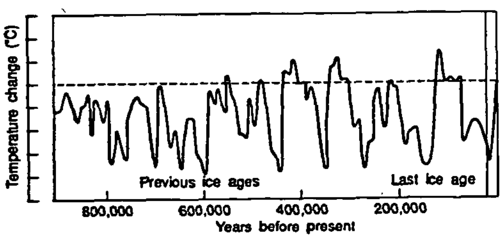

Figure 5

HISTORIC TEMPERATURE VARIATIONS

(dashed line = 1900)

Source: Ref. 4