CLIMATE CHANGE AND ENERGY OPTIONS: DECISION MAKING IN THE MIDST OF UNCERTAINTY

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Understanding the world's natural systems, and how our own activities may be affecting those systems, are crucial for the long-term well-being of our society and of all the inhabitants of this world. One of the most complex of these is the global climate system. The nature and extent of significant alterations to the global climate system due to increasing emissions of greenhouse gases, resulting from human activity such as energy production and manufacturing processes, is still the subject of considerable uncertainty and, indeed, controversy. However, the possible consequent effects on ecological systems and human society may be of such profound gravity, that continuing research into the causes and effects of climate change, and development of viable technology solutions for mitigation of these effects, are essential. Understanding the global climate system, determining how our activities may be influencing it, and taking responsible actions to protect it for future generations, may be among the greatest challenges that humanity has ever faced.

Background

For over a hundred years, scientists have been carefully gathering and verifying data on the Earth's temperature and precipitation patterns. The most recent data reveal some striking trends:

- 12 of the warmest years in this record occurred during the 17 years prior to 1998. New temperature records continued to be set in 1997, and the average global temperature in 1998 was higher than it had been during the previous 1,000 years [1].
- In large areas of the United States, temperature increases in a range of 2 - 4 °F (1 - 2 °C) have been measured during this century.
- The global average surface temperature has risen approximately 0.7 °C (1.2 °F) in the past 100 years.

Until recently, climate scientists were uncertain whether these developments reflected natural variations in the Earth's climate, or whether in fact human activities contributed to this warming. But in 1995, in the largest peer-reviewed international scientific assessment of any scientific issue ever undertaken, the Intergovernmental Panel on Climate Change – an international body charged with studying this issue – reached the conclusion that the observed increase in global average temperature during the 20th century "is unlikely to be entirely natural in origin" and that "the balance of evidence suggests that there is a discernible human influence on global climate" [2]. Subsequent analyses of these data affirmed that the warming trend in the second half of the 20th century could "exclude purely natural forcing, and [be] attributed largely to the anthropogenic components" [3].

The Earth's climate is the result of extremely complex interactions among the atmosphere, the oceans, the land masses, and living organisms – including human industrial activity – all of which receive energy from the sun. This energy ultimately radiates back into space, but a sufficient fraction is retained in the Earth's atmosphere to maintain an average temperature of approximately 15°C (59°F). This temperature is maintained by energy absorption in heat-trapping gases (the "Greenhouse Gases", or GHG's), which include water vapor, carbon dioxide, ozone, nitrous oxide, methane, and several trace gases of industrial origin (CFC's, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride). Over the course of the Earth's history, living creatures have evolved and adapted to function optimally in this temperature regime, and in turn human society has organized itself to function as well as possible in this climate.

During the past 150 years, atmospheric levels of many GHG's (except water vapor, which is controlled by evapotranspiration and precipitation) have undergone significant increases, recently at an accelerating pace. The connection between GHG emissions and temperature change is not merely that the two seem to be correlated in time, but also that detailed physical models of the atmosphere predict the global warming effect. The magnitude of the effect, however, is subject to considerable uncertainty, as a result of still imperfect knowledge about the interplay between GHG's, atmospheric water vapor, ozone, clouds, aerosols, and particulates. If carbon dioxide concentrations were to double over current levels during the next 100 years – a possible scenario given the trend of economic development – current models predict overall global average temperature increases somewhere between a low estimate of 1 °C (~2 °F) and a high estimate of 3.5 °C (6.5 °F). Furthermore, because of the long residence time of carbon dioxide in the atmosphere, increased CO_2 levels due to fossil fuel combustion will persist long after emissions are reduced [4].

While the low estimate given above may indeed present few challenges, the high estimate – which is just as likely to be true as the low estimate – would have extremely serious consequences. During the last great Ice Age which ended 10,000 to 12,000 years ago, during which the northern U.S. and Europe were covered with a sheet of ice a mile thick, global average surface temperatures were only about 5° C lower than they are today. A global average surface temperature 2 °C higher than current levels would be unprecedented in recent human experience, and an increase of 5° to 6° would correspond to the climate which prevailed during the age of the dinosaurs! It should be noted that these predicted temperature rises are not uniform, but would be significantly higher than the average in specific parts of the Earth, particularly in the Polar regions. Most significantly, these changes are predicted take place, not over geological times of thousands or millions of years, but within a few decades or centuries, far more rapidly than natural ecosystems are able to evolve or adapt.

The possible consequences of this predicted change in global average temperature range from modest, in some cases even benign effects, to severe effects which are difficult to predict with any accuracy but which could be truly catastrophic if they occur. There is a wide variation in the level of confidence with which any specific effect can be forecast [5]; however, all of the following have been predicted on the basis of plausible models and assumptions.

- Increased number and severity of heat waves, droughts, and other extreme weather events which place stress on plant and animal species, including humans.
- Since an increased temperature enables the air to hold larger amounts of water vapor, major changes in precipitation patterns could occur, wreaking havoc with current agricultural practices.
- Ranges and habitats of a wide variety of plant and animal organisms could be affected. This could lead to loss of many species, including many beneficial to humanity, as well as exposure of vulnerable populations to disease-bearing organisms such as mosquitoes, ticks, and rodents.
- Sea levels could rise by 1 foot to as much as 5 feet by year 2100, due to loss of polar and landlocked ice and thermal expansion of the oceans. This would submerge significant areas of low-lying, populated territories, affect the salinity of estuaries and coastal aquifers, and damage or destroy wetlands and coral reefs responsible for much of the ocean's biological productivity. Several scientists have suggested the possibility of even larger sea level rises resulting from breakup of polar ice sheets.
- Projected precipitation increases at higher latitudes could also act to reduce the ocean's salinity and therefore its density. This, in turn, might interfere with oceanic circulation patterns – possibly altering or even suppressing the Gulf Stream which maintains Europe's current temperate climate [6].

Conclusions

In arriving at an appropriate course of action in the face of profound uncertainty about both the magnitude and effects of human-induced climate change, and its impacts on life on Earth and on human economic activity, we must consider both the costs of taking action and the considerable risks of taking no action [7]. International agreements are now under consideration which will begin to limit allowable levels of GHG emissions. Numerous questions still exist among governments, the scientific community, and the general public about the need for such agreements and the most effective technological, economic, and political strategies to achieve such emission limits. A vigorous and well-coordinated research effort is needed to narrow these uncertainties and to develop science and technology options in the case that rapid responses to changing climate conditions become necessary. We recognize, however, that we may never succeed in eliminating all the uncertainties surrounding the climate change issue, and that it may be necessary to take action, sooner rather than later, even in the face of such uncertainties. The longer action is delayed, the more difficult and costly it will be to institute limits on GHG emissions should such limits prove to be necessary.

Many uncertainties remain in the area of Global Change Science, and research still needs to be carried out to reduce these uncertainties. Among these are:

- the effects of clouds, aerosols, particulates, and especially atmospheric water vapor on climate change;
- the coupling between overall global climate change and regional climate variations;
- ocean-atmosphere interactions;
- effects of climate changes on both ecological and social-economic systems.

In addition to continuing to study the basic phenomena of climate change, modern industrial societies must begin to take action to address this issue. Climate change has "massive market transforming potential" [8], with potential impacts on many industry sectors including petroleum and other energy resources, energy production, transportation, agriculture, residential and commercial construction, and not least the chemical industry. Making the transition to a more energy-efficient, less carbon-intensive economy presents a tremendous long-term economic opportunity for those industries willing to undertake the necessary research and development, and invest in the new technologies that will achieve these goals. Some of these opportunities include:

- Chemical manufacturing processes may be redesigned to improve energy efficiency and reduce GHG emissions while reducing or eliminating production of toxic waste. These goals have been summarized in *Technology Vision 2020: The U.S. Chemical Industry* [9] and are the basis of "Green Chemistry" strategies [10].
- Carbon dioxide sequestration may offer a route to partial reduction of net emissions. CO_2 could be captured in industrial processes and removed from the atmosphere by reforestation and planting, which also benefits habitat and biodiversity preservation.
- Alternative energy sources should be developed which minimize GHG emissions, such as advanced fossil-fuel technology, fuel cells, renewable energy technologies such as biomass, wind, and solar energy sources, and nuclear power [11].
- In addition, proposed GHG and carbon emission limits may have a significant *indirect* impact on chemical process industries, since changes in refinery product streams, driven by alternative fuel demand, may affect chemical feedstock availability. A systematic study of such interactions needs to be undertaken, and alternative sources of starting materials identified.

Attaining an understanding of how the global climate system operates and how our own activities may be influencing it, and of undertaking responsible actions to protect that system for the well-being of future generations, may be among the greatest challenges that humanity has ever faced. Arriving at the necessary decisions and taking appropriate actions in the face of substantial uncertainty is neither new nor unfamiliar in our society – corporations always have to make business plans for an uncertain future, and individuals do this whenever they purchase an insurance policy or set up an estate plan. The climate system, on which the global ecology and economy depend, deserves at least the same degree of care and attention. Research on Climate Change and its possible effects must be continued and strengthened, the public must be informed and educated about this issue, industry must adopt proactive strategies for energy conservation and greenhouse gas reductions, and prudent and responsible actions must be undertaken as needed to address this challenge which confronts us all.

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References

1. M.E. Mann, R.S. Bradley, and M.K. Hughes, "Northern Hemisphere temperatures during the past millennium: Inferences, uncertainties, and limitations", Geophys. Research Letts. **26**, 759 – 762 (1999).
2. J.T. Houghton, L.G. Meira Filho, et al. (Eds.), Intergovernmental Panel on Climate Change: *Climate Change 1995: The Science of Climate Change* (Cambridge University Press, Cambridge, UK, 1995).
3. S.F.B. Tett, P.A. Stott, M.R. Allen, W.J. Ingram, and J.F.B. Mitchell, "Causes of twentieth-century temperature change near the Earth's surface", Nature **399**, 569 – 572, (1999).
4. P.P. Tans, "Why carbon dioxide from fossil fuel burning won't go away", in D.L. Macalady (Ed.), Perspectives in Environmental Chemistry, pp. 271 –291 (Oxford University Press, Oxford, UK, 1998).
5. J. Mahlman, "Uncertainties in projections of human-caused climate warming", Science **278**, 1416 – 1417 (1997).
6. T.F. Stocker and A. Schmittner, "Influence of CO_2 emission rates on the stability of the thermohaline circulation", Nature **388**, 862 (1997);
   W.S. Broecker, "Thermohaline circulation, the Achilles Heel of our climate system: will man-made CO_2 upset the current balance?", Science **278**, 1582 (1997);
   R.A. Kerr, "Warming's unpleasant surprise: Shivering in the Greenhouse", Science **281**, 156 (1998).
7. H.D. Jacoby, R.G. Prinn, and R. Schmalensee, "Needed: A realistic strategy for global warming", MIT Joint Program for the Science and Policy of Global Change, Report No. 21 (Cambridge, Mass., August 1997).
8. D.L. Levy, "Strategic Responses to Climate Change in the Automobile Industry: An International Comparison", Environment and Sustainability Seminar (MIT, September 1999).
9. American Chemical Society, American Institute of Chemical Engineers, Chemical Manufacturers Association, Council for Chemical Research, and Synthetic Organic Chemical manufacturers Association, *Technology Vision 2020: The U.S. Chemical Industry* (Washington, D.C., December 1996).
10. P.T. Anastas and J.C. Warner, *Green Chemistry: Theory and Practice* (Oxford University Press, Oxford, UK, 1998).
11. President's Committee of Advisors on Science and Technology, Panel on Energy Research and Development, "Report to the President on Federal Energy Research and Development for the Challenges of the Twenty-First Century" (Washington, D.C., September 1997).