SCIENTIFIC AND INTERNATIONAL POLICY RESPONSES TO GLOBAL CLIMATE CHANGE

WILLIAM R. MOOMAW

Unintended pollution and ecological change have always been an integral consequence of human activity. One need only examine the middens and dwellings left by our paleolithic and neolithic ancestors to see that solid waste disposal and indoor air pollution are not newly discovered problems. Prior to the beginning of the industrial revolution 200 years ago, however, human-induced environmental change, whether intentional or not, was strictly a local matter. The rapid growth of the human population to more than 5 billion people in combination with increasingly powerful and pervasive technologies is today altering both the regional and global environment.

THE HISTORICAL RECORD

The worldwide distribution of the effluents of our civilization are abundantly evident in numerous sediments, ice fields and living organisms, and reveal the profound connection between human actions and the many components of the biosphere. It is perhaps not too surprising to find the record of our increasing use of toxic metals such as lead, mercury and cadmium recorded in the bottom sediments of lakes and bogs throughout the United States and in the snowfields of the Sierra Nevada mountains of California. However this same record is echoed in the far distant glaciers of Greenland and Antarctica, where these materials were never used until recently. The same kind of evidence exists for pesticides such as DDT which also appears in remote ice core samples and in the fat of penguins, seals and people who live many thousands of miles from where the pesticides were released.

Also trapped in the permanent ice fields of Greenland and Antarctica by the annual deposits of falling snow are small bubbles of "fossil air" that provide us with a continuous record of atmospheric composition which now extends backward in time to include the past 160,000 years.[1]

The atmosphere is composed primarily of nitrogen and oxygen which together make up 99 percent of dry air. Inert argon accounts for all but about 4/100 of the remaining 1 percent, which is accounted for by a host of trace gases which are measured in parts per million (ppm), parts per billion (ppb)

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[1] J. M. Barnola et al., "Vostok Ice Core Provides 160,000-Year Record of Atmospheric Carbon Dioxide." *Nature* 329 (1987): 408-414.

and even parts per trillion (ppt). Water vapor is a highly variable component which can range from essentially zero to a few percent of atmospheric composition.

The primary trace gas is carbon dioxide which is produced by animal and plant respiration and is the principle building block of all photosynthetic plants. An analysis of recent ice cores reveals that in the mid-18th century, prior to the industrial revolution, carbon dioxide was present at levels of 280 ppm (a little more than one molecule in 4,000).[2] As can be seen in Figure 1, concentrations increased gradually for about a century as the result of the deforestation of Northern Europe and eastern North America. The large amount of carbon in trees is released as carbon dioxide when they are burned

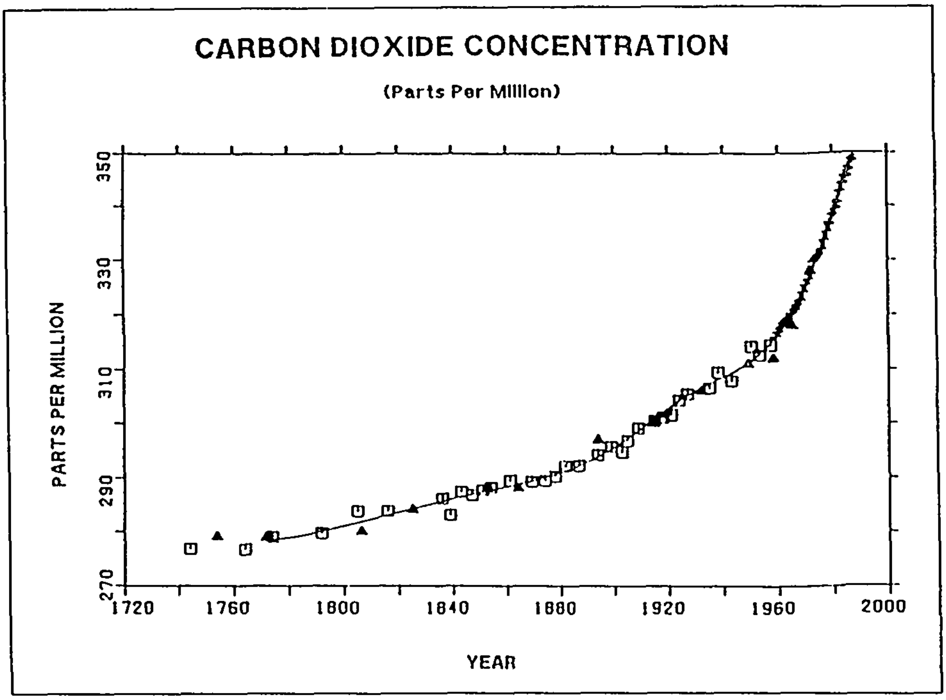

Figure 1. The average concentration of carbon dioxide found in air bubbles trapped in the Greenland and Antarctic glaciers is plotted in parts per million as a function of the year in which it was trapped in the ice. The crosses represent direct measurements made in the atmosphere by C. David Keeling at Mauna Loa in Hawaii. This graph is adapted from *Policy Options for Stabilizing Global Climate*, D. A. Lashoff and D. Tirpak, eds. 1990 in press. US Environmental Protection Agency, Washington, DC.

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[2] D. A. Lasahoff and D. Tirpak, eds., *Policy Options for Stabilizing Global Climate* (Washington, D.C.: Environmental Protection Agency, forthcoming).

or allowed to decay. By the middle of the 19th century, industrializing Europe and North America were powering their economies with coal and peat thereby accelerating the growth of atmospheric carbon dioxide. The most rapid growth, however, has occurred in the second half of the 20th century as coal burning accelerated and was converted along with oil and natural gas to heat, carbon dioxide, water vapor and a mixture of now all-too-familiar air pollutants. In 1989 an estimated 5.5 billion metric tons of carbon[3] (slightly more than one ton for every person on earth) were released into the atmosphere by the combustion of fossil fuels and, for the first time, carbon dioxide levels were measured in excess of 350 ppm[4], a full 25 percent increase above preindustrial levels. Tropical deforestation has also increased dramatically and is believed to contribute an additional 20 percent or so. Annual atmospheric carbon dioxide growth has averaged nearly 0.5 percent but has surged unexplainably during the past three years.[5]

The glacial record also reveals that methane has remained relatively constant for 10,000 years at around 700 ppb. In the past century, however, methane concentration has soared to 1,700 ppb and continues to grow at a rate of 1 percent per year.[6] By-products of combustion like ozone, a principle component of smog, and synthetic chemicals such as chlorofluorocarbons (CFCs) are also altering the composition of the atmosphere as a result of our economic activity.

> . . . the warming predicted to result from a doubling of carbon dioxide alone in 2075 will occur as early as 2030.

But why should the concentrations of atmospheric trace gases be of concern to anyone other than a few specialized scientists intent on accurately measuring changes in miniscule quantities of invisible gases? It turns out that the trace gases along with water vapor are the atmospheric components that act as a thermal blanket for the planet by slowing the release of radiant heat from the earth to outer space. This phenomenon, the so-called greenhouse effect, appears to have sprung full blown into the public consciousness during the past few years. In fact, the notion first appeared in print over 160 years ago and has been forgotten and rediscovered by the scientific community at least four times.

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[3] Extrapolated from data compiled in *World Resources 1988-89* (Washington, D.C.: World Resources Institute, 1989).

[4] C. David Keeling, *Tellus* (forthcoming).

[5] Ibid.

[6] *World Resources 1988-89*

Questions and speculations about the origin and age of the earth and its myriad species were well developed by the first quarter of the 19th century, even though the scientific knowledge needed to address these issues specifically was largely unavailable. Climatology may have gotten its start when physicists became intrigued with the question of how the earth managed to maintain its relatively warm temperature. It was the great French mathematical physicist Jean Fourier who argued that the atmosphere acted like the glass of a greenhouse by letting in the visible rays and energy of the sun, but impeded the radiation of heat from the warm earth back into cold outer space.[7] Fourier missed the point that glass also helps greenhouses stay warm by keeping the warm, solar-heated air within from mixing with the cooler air outdoors. Nevertheless, his misnomer has persisted, and atmospheric absorption of radiant heat is still commonly referred to as the greenhouse effect.

In 1896, the productive Swedish chemist, Svante Arrhenius, took recently acquired data on the infrared-absorbing properties of carbon dioxide and water, and combined it with Samuel P. Langley's measurement of solar intensity to produce the first quantitative calculation of atmospheric warming. He correctly concluded that although their presence was minute, water and carbon dioxide molecules together absorbed enough radiant heat to raise the earth's temperature by nearly 33°C (60°F).[8] Instead of being an ice-bound, frozen planet, earth had a climate amenable to the carbon-based biochemistry that has given rise to approximately 10 million living species.

Not satisfied with merely establishing the correctness of this important insight, Arrhenius went on in his paper to address the question of what would happen if industrial societies continued to add carbon dioxide to the atmosphere through the burning of fossil fuels such as coal, oil, natural gas and peat. After a rather detailed analysis, he concluded that a doubling of atmospheric carbon dioxide would raise the average global temperature by an additional 5.5°C (10°F), later revised to 4°C (7°F).[9] His calculations compare favorably with the best current estimate of 1.7-5°C (3-8°F), which is based upon better data and more elaborate analysis. In other words, Arrhenius correctly deduced that increasing the amount of carbon dioxide in the atmosphere can turn the greenhouse into a "heat trap" as Norway's former Prime Minister, Ms. Gro Harlem Brundtland, recently termed this overheating.

A British engineer, G. D. Callendar, in 1938, carried out the first direct comparison between the measured growth of carbon dioxide in the atmosphere and long-term temperature records from 200 meteorological stations. The response to Callendar's paper that concluded that warming had been observed and was consistent with increases in atmospheric carbon dioxide was greeted with skepticism by the British Royal Society to which it was presented.

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[7] M. Fourier, "Memoire sur les temperatures du globe terrestre et des espaces planetaires," *Mem. de l'Academie Royal des Sciences de l'Institute de France* 7: 569-604.

[8] S. Arrhenius, "On the Influence of Carbonic Acid in the Air Upon the Temperature on the Ground," *Philadelphia Magazine: Journal of Science* 41 (1896): 237-276.

[9] S. Arrhenius, *Worlds in the Making: The Evolution of the Universe* (London and New York: Harper and Row Publishers, 1908).

Callendar was undaunted and moreover was optimistic that the added carbon dioxide was "likely to prove beneficial to mankind in several ways" as increased "mean temperature would be important at the northern margin of cultivation." He also felt that plant growth would improve with increased carbon dioxide in the atmosphere, and, "In any case the return of the deadly glaciers should be delayed indefinitely."[10]

During the 1970s, attention was focused on atmospheric problems such as urban air pollution and the depletion of the stratospheric ozone layer that seemed unrelated to global warming. It was only a decade later that their significance for the greenhouse effect would be fully recognized. An atmospheric scientist at the University of Chicago, Veerabhadran Ramanathan, first pointed out in the mid-1970s that the chlorofluorocarbons (CFCs), at that time only suspected of being stratospheric ozone depleters, shared with carbon dioxide the radiant-heat-absorption properties that cause global warming. His initial claim went largely unnoticed because the concentration of carbon dioxide was 500,000 times greater than that of CFCs; it was thought that CFCs would have only a negligible effect on global temperatures. Over the next ten years, Ramanathan and Ralph Cicerone of the National Center for Atmospheric Research at Boulder, Colorado, showed that each CFC molecule produced a warming effect nearly 20,000 times that of an added molecule of carbon dioxide. Measurements revealed that the additions of these commercial chemicals to the atmosphere were increasing at ten times the carbon dioxide growth rate.[11] These researchers further demonstrated that other greenhouse gases were accumulating rapidly in the atmosphere.

INTERPRETING THE DATA

Their findings have startling implications. These additional gases now contribute as much to global warming as does carbon dioxide. Projecting into the future, the combination of growth in all of the greenhouse gases means that the warming predicted to result from a doubling of carbon dioxide alone in 2075 will occur as early as 2030.[12] This is well within the lifetime of many people living today.

One might well question whether a few degrees of warming is a cause for concern, or indeed if the consequences might not even be beneficial. The mid-range projected increase of 3°C (5°F) by the third quarter of the next century is a bit over half the temperature rise that occurred between the time the earth moved from the depths of the last great ice age 10,000 years ago and the present. These projections are based upon large computer models that require the world's largest and fastest computers. Even so, the models are still

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[10] G. D. Callendar, "The Artificial Production of Carbon Dioxide and Its Influence on Temperature," *Quarterly Journal of the Royal Meteorological Society* 64 (1938): 223-237.

[11] V. Ramanathan et al, "Trace Gas Trends and Their Potential Role in Climate Change," *Journal of Geophysical Research* 90 (1985): 5547-5566.

[12] I. Mintzer, "A Matter of Degrees, The Potential for Controlling the Greenhouse Effect," World Resources Institute, 1987; J. Hansen, M. Lacis and J. Prather, *Geophysical Research* 94 (1989): 16, 411-417, 421.

somewhat crude and there is still a great deal we need to learn about the operation and interaction of the atmosphere, oceans and the biosphere.

Because of many gaps in our knowledge, predicting the consequences of an enhanced greenhouse effect is far from being a precise science. Nevertheless, a number of more or less likely consequences have been identified and are being studied. One conclusion seems quite clear. First, although the projected rise in temperature of approximately half a degree per decade may seem slow, it is five to ten times as fast as global climate change in the past. The rapidity of such change may introduce instabilities in climate and is certain to be devastating to forests and other natural ecosystems that cannot migrate at such a rate. Second, it is not just the average rate of change that will create the most acute problems, but rather the intense, short term fluctuations that deviate from that higher average.

Although the projected rise in temperature of half a degree per decade may seem slow, it is five to ten times as fast as global climate change in the past.

Some specific consequences of climate change that may be anticipated include the following.[13] Warmer average temperatures and more frequent and intense summer heat waves can be expected. This will produce a greater demand for summer cooling power, and a lowered demand for winter space heating. Altered temperature patterns will shift rainfall patterns, monsoons and perhaps ocean currents. Patterns of drought similar to those observed in the midwestern part of the United States in 1988 could reduce grain output significantly. Existing irrigation systems might not meet the design needs of altered precipitation and demand patterns. Regions with lower rainfall would experience reduced availability of power plant cooling water and interrupted river barge traffic as also occurred in 1988. Regions near the coasts and poles are expected to experience an increase in rainfall.

Ecosystems such as forests and coral reefs could be altered drastically, especially if climate change is rapid. This in turn could lead to major extinctions and a decline in biological diversity.

Carbon dioxide increases are expected to increase the growth rate of many plant species provided that water and other nutrients remain abundant. This

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[13] This list represents a compilation by the author of effects that have been proposed by many sources, including: *Current Issues in Atmospheric Change* (Washington, D.C.: National Academy Press, 1987); *Policy Options for Stabilizing Global Climate* (Washington D.C.: Environment Protection Agency, 1989, forthcoming); and "Developing Policies for Responding to Climate Change," WCIP-1, WMO/TD No. 225 World Meteorological Organization and United Nations Environment Programme, 1988.

could be a boon to agriculture and forestry that have not been damaged by higher temperatures, but would alter the relative competitiveness of plant species and insects and other pathogens.

Warmer temperatures will increase the amount of water evaporated into the atmosphere increasing both its heat trapping capacity and the amount of cloud cover. Current clouds reflect more incoming solar energy into space than they trap radiant heat from earth, leading to less warming than under a totally cloudless sky. Work is currently under way to determine whether future cloud patterns in a warmer world will enhance or mitigate future warming.

Warmer tropical waters are expected to spawn more intense hurricanes and typhoons, and some climatologists predict an increasing frequency of extreme weather events.

But is there any evidence that the earth has warmed? In some locations, temperatures have been recorded continually for over 100 years. Two research groups, one in England under Thomas Wigley and a second in the United States under James Hansen, have analyzed millions of individual measurements from all over the globe. They have had to exercise great care, since not all data are equally reliable, and higher urban temperatures must be corrected for the local heat islands created by the concentrated release of energy from cars and buildings. After carefully evaluating all such factors, both groups independently concluded that there has been a rise of about 0.5°C (1°F) during the past century, and that nearly half of that rise has occurred since 1965[14] (See Figure 2). Hansen caused a major commotion in June of 1988, when he testified before Congress that, based upon a statistical analysis of the data, there was a 99 percent certainty that the recent increases lay outside the range of normal temperature fluctuations. In other words, the earth's climate, which is defined as the thirty-year average of temperature (and weather), may be changing.

At this point it is important to ask a question: is the observed temperature rise caused by the buildup of greenhouse gases? The answer is a resounding "maybe." It is enormously difficult to prove cause and effect, especially when they are separated in time and linked by a complex set of interactions. It is even more difficult to convince policymakers and the public of the connection when many of the measurements and the theory linking them are known only to a relatively small group of scientists. Just remember how difficult it was to convince governments and industry that the benign chemicals (CFCs) used to operate our refrigerators and air conditioners, that also provide us with insulation and foam for our mattresses and chairs, and that keep our computers and communications systems functioning, were the cause of ozone loss in the stratosphere. Researchers assembled many pieces of evidence over more than a decade to persuade governments that a problem existed, and it required the discovery of the Antarctic ozone hole to capture the attention of the world. It is now estimated that even if we were to halt the release of all CFCs

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[14] J. Hansen et. al., "Regional Greenhouse Effects," in *Coping with Climate Change* (Washington, D.C.: Climate Institute, 1988), 102-107; also, Lachenbruch and Marshall, *Science* 234 (1986): 689.

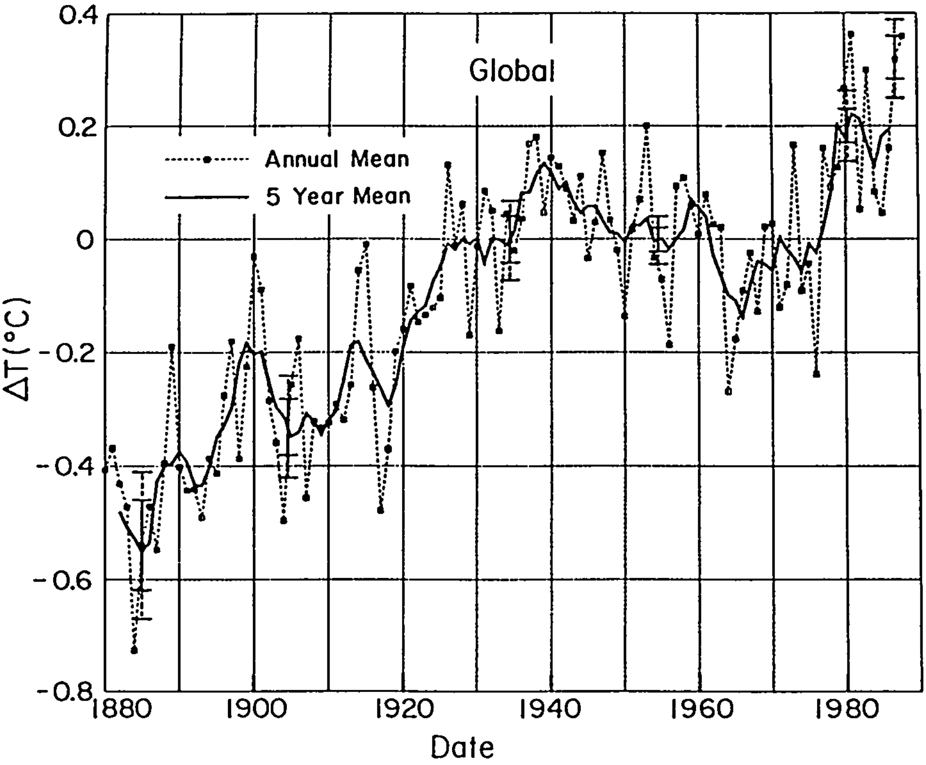

Figure 2. The annual change on the global temperature from the average of the reference period 1951-1980 is plotted for each year from 1860 through 1988. To convert to degrees Fahrenheit, multiply by 1.8. Note the levelling and slight decline that occurred between 1940 and 1965, and the sharp rise that has occurred since then. This graph was published in a paper, "Regional Greenhouse Climate Effects" by J. Hansen et al in *Coping With Climate Change*, John C. Topping, ed. June 1989, The Climate Institute, Washington, DC, pp. 68-71.

immediately, it would require one to three centuries for the ozone hole to heal itself by natural processes. We probably cannot afford to wait for a similar event to dramatize the danger of greenhouse gases. By the time the greenhouse effect is noticeable to the person on the street, we will have committed ourselves to substantial additional warming that will take decades to reverse.

FORMULATING A RESPONSE

What is clearly needed is a greenhouse early warning system. To develop such a system we must determine what additional consequences are expected to arise from global warming. We could then search for a pattern of such events which would define a kind of "greenhouse warming fingerprint." We must build a plausible case based upon a collection of factors, none of which may be convincing by itself, but when taken together could provide a framework for judging whether or not our atmosphere has become a heat trap.

Two principal elements are already in place. The first is the direct observation of an increase in greenhouse gases, and the second is the measured rise in temperature. We know, however, that there is uncertainty in the earlier temperature measurements, and no one has a complete explanation for the leveling and slight decline in temperatures that occurred between 1940 and 1965. The two warmest years in the last hundred or so years were 1987 and 1988 and the 1980s are the warmest decade ever recorded. Does this prove that we are in a greenhouse warming trend? If next year is cooler, does that mean that the warming trend is over? The answer to both questions is no. What else can we look for?

By the time the greenhouse effect is noticeable to the person on the street, we will have committed ourselves to substantial additional warming that will take decades to a century to reverse.

The greenhouse theory predicts that we will see a non-uniform warming of the globe, with greater temperature increases at the poles. As warming occurs one would expect melting of highly reflective ice and snow and greater heat absorption by the newly exposed darker land and water. While there are relatively few long-term temperature data from the polar regions, indirect information suggests that permafrost in some areas may have warmed up by as much as 4°C (7°F), substantially more than the global averages, during the past century.[15] Tibetan ice cores also reveal that the past half century was the warmest since the last ice age.[16] The observed warming does have the general latitudinal distribution predicted by theory, but differs in several important details. Certainly we should carefully observe the distribution of warming and pay special attention to high and low latitudes where larger, more easily observed increases in temperature are likely. Another clue we should search for in the greenhouse fingerprint is the poleward migration of animal and plant species, and the loss of heat-intolerant species near the warmer margin of their range.

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[15] A. H. Lachenbruch, "Warming of Permafrost in the Alaskan Arctic," in *Preparing for Climate Change* (Washington, D.C.: Climate Institute, 1988), 102-107.

[16] L. G. Thompson et. al., "Holocene-Late Pleistocene Climate Ice Core Records from Qinghai-Tibetan Plateau," *Science* 246 (1989): 474-477.

Tidal records show that sea level is currently rising at a rate of one inch per decade[17], and the United States is currently experiencing beach erosion along three-quarters of its coastline. Research by Stephen Leatherman at the University of Maryland shows that barrier islands, which protect coasts, are especially vulnerable to sea level rise.

Among the uncertainties is the fate of nearly half the carbon dioxide that is released into the atmosphere. It is assumed that it dissolves in the ocean, but ocean circulation and the biological cycling of carbon are still not very well understood. We know even less about the sources of the rising amounts of atmospheric methane. Part of the increase appears to be related to our agricultural practices, and some to landfills, natural gas leaks and deforestation. Are there surprises ahead for us like those that occurred with the Antarctic ozone hole? Walter Broecker at Columbia University has raised the possibility that changes may not be gradual, but sudden and discontinuous.[18] He has suggested that ocean currents may suddenly shift in response to temperature changes. Were the warm currents of the Atlantic, for example, to shift south, we could witness the anomaly of a colder Europe in a warmer world.

Over time the range of uncertainty can be expected to narrow, as researchers obtain new information and refine and test their models. There are, in fact, some very important observations that help to put the greenhouse effect into a larger context.

One of these came to light in 1987 when a Soviet team drilled a deep ice core 2,000 meters deep near its research station at Vostok, in Antarctica. French researchers cooperated in analyzing air samples trapped in the ice and determined their age. From isotope data it was then possible to estimate the global temperature at the time each sample was trapped.[19] The findings are very intriguing. During the past 160,000 years, carbon dioxide levels have varied directly with temperature. During a very warm interglacial period 130,000 years ago, carbon dioxide levels were just under 300 ppm. Levels dropped to around 200 ppm during the last great ice age, then climbed to 280 ppm as the world entered the current interglacial warm spell. In only 200 years we have reached 350 ppm, with more than half of this rise occurring in the past 30 years. The other principal naturally occurring greenhouse gas, methane, follows a similar pattern. Ice ages and sharply warmer interglacial periods are known to be triggered by motions of the earth in its orbit around the sun that change the amount and distribution of solar energy received. It is believed that the rise in greenhouse gas concentrations is a positive feedback that magnifies the temperature changes. Additional factors including a possible reorganization of ocean atmospheric interactions that accompany the altered

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[17] W. R. Peltier and A. M. Tushingham, "Global Sea Level Rise and the Greenhouse Effect: Might They be Connected?" *Science* 244 (1989): 806-810.

[18] W. Broecker, "Unpleasant Surprises in the Greenhouse?" *Nature* 328 (1987):123-126; also W. S. Broecker and G. H. Denton, "What Drives Glacial Cycles?" *Scientific American 1990*: 49-56.

[19] J. M. Barnola et. al., 1987.

heat-trapping capacity of the atmosphere lead to the regular and dramatic changes observed in the earth's climate.

The fact that the global climate system is for the first time being driven by additions of heat-trapping gases outside the known atmospheric regime, just as we are at the peak of an interglacial warming period, has caused some scientists to speculate about the consequences. George Woodwell has raised the possibility that additional warming might trigger a runaway greenhouse effect as additional carbon dioxide and methane are produced by the decomposition cycle in a warmer world. Gordon MacDonald has also warned that warming may release vast quantities of methane from the thawing Arctic tundra and the sea floor of the shallow Bering Sea.

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We must keep such lessons in mind as we conduct our own planetary greenhouse experiment. While we watch for an unambiguous greenhouse warming signal, we are faced nevertheless with some degree of uncertainty. And yet we need to fashion a response. Humankind is a bit like a driver speeding down the highway at 65 miles an hour who suddenly enters a fog bank. Ahead, a dim flashing yellow warning light can be seen. Perhaps everything is alright and the driver can maintain his speed. But, then again, perhaps the bridge is out or there is an accident ahead. In the case of global warming we are a bit "in the fog" in terms of what we know, but we have seen a caution light. To date our response has been to step harder on the accelerator rather than to slow down while we find out whether it is safe to proceed as before. Those who argue that we should begin to slow the rate of release of greenhouse gases suggest that to be the prudent course of action.

THE POLITICAL IMPERATIVE

In January 1989 the Intergovernmental Panel on Climate Change (IPCC) began an eighteen-month investigation into the scientific basis of the greenhouse effect, its consequences and available policy options under the leadership of the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). The Panel will report its recommendations to the World Climate Conference in November 1990. President Bush addressed the IPCC in February 1990 and took an exceedingly cautious approach, calling for more research and reiterating his concern that economic development in a free market not be impaired by responses to climate change. At the Paris economic summit in July 1989, the seven major economic powers called for concerted action to address global warming although they were short on specifics.

In November 1989, Environmental Ministers from sixty-eight nations met at Noordwijk, the Netherlands and issued a statement that read, "In the view of many industrialized nations such stabilization of carbon dioxide emissions should be achieved as a first step at the latest by the year 2000." This was actually a weaker statement than the one initially proposed that called for setting a cap on carbon dioxide emissions by the year 2000 and cutting them by 20 percent within five years. That position was opposed by the United States and Japan with support from the Soviet Union. Sweden actually has passed legislation that requires such a cap, the prime minister of Norway has pledged that Norway will also stabilize its emissions by 2000 and the Dutch have stated a goal of reducing their emissions by 2 percent per year over the next three years. While the federal government has refused so far to take action in the United States, Congress is moving legislation forward and many individual states are enacting climate stabilization acts.

There clearly is a need, if the nations of the world do move toward global limitations on greenhouse gases, to provide some mechanism for technology transfer to newly industrializing countries and to Eastern Europe. In fact, several nations have called for the availability of such technology on a non-commercial basis. A strong disagreement lingers between nations. India argues that there is an obligation to supply technologies that address global environmental problems to nations who cannot develop them while the United States supports the principle of intellectual property rights. Benjamin Read, a former assistant secretary of state, has suggested the need for a new concept of eminent domain that might bridge this gap by providing compensation for products that are essential to the global community, but which otherwise might not be available. A proposal to establish a multilateral development fund to promote technology transfer enabling developing countries to respond to international calls to reduce greenhouse gas releases was strongly opposed by the United States at Noordwijk. The proposal is supported strongly by several European governments. The Noordwijk meeting did join world leaders such as Prime Minister Thatcher and President Gorbachev in calling for a framework convention to address climate change by 1991 or 1992 at the latest.

How might the United States respond to an international agreement to curb its release of greenhouse gases? Learning to use fossil fuels twice as efficiently as we now do would put our economy and high standard of living on the same basis that Western Europe enjoys. This improved energy efficiency—combined with replacing coal with natural gas, which produces half the carbon dioxide per unit of energy, and rapidly reducing the use of CFCs during the next decade—would slow the rate of global warming while we develop solar and other non-carbon dioxide-producing energy technologies.

We should begin with those strategies that are the most cost effective and which address other problems such as air pollution, stratospheric ozone depletion and balance of payments problems. Many energy efficiency options, in fact, have been shown not only to pay for themselves, but actually to provide a high rate of economic return in addition to protecting the environment.

The United States was forced to begin this process with the disruptive oil shocks of the 1970s. Although US carbon dioxide releases have fluctuated in inverse proportion to the price of energy between 1973 and 1988, it is generally not recognized that the average annual emissions of carbon dioxide during that sixteen-year-period is below what it was in 1973![20] This "stabilization" of carbon dioxide occurred despite the fact that the US population grew by 15 percent during that period, the gross national product grew by 45 percent and we had active policies promoting the use of coal for most of that period. We accomplished this by improving the economic efficiency with which we utilize energy. For nearly a decade, energy per dollar of GNP dropped almost 3 percent per year. Imagine what might have happened had we had an active policy to promote greenhouse gas reductions. Unfortunately, 1987 and 1988 saw US carbon dioxide emissions rise to record highs in terms of absolute quantities, and also for the first time in many years we increased our global share.[21] It appears that 1989 will have continued this trend.

At the Global Forum held in Moscow in January 1990, President Gorbachev stated that *perestroika* had caused him to see both ecology and economics in a different light. If we are to respond to the likely threat that we are turning our atmospheric greenhouse into a heat trap it will be necessary for each nation to carry out its own *perestroika*: to develop an economy that does not undermine itself and other nations through its effluents. It is also essential that we begin the task of restructuring soon if we are to obtain the insurance we need in time, just in case the greenhouse fingerprint appears clearer and sooner than we expect.

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[20] J. MacKenzie, Working Paper Prepared for the World Resources Institute, Washington, D.C.

[21] Ibid.