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Rushing to Judgment

Is Earth warming? The planet has warmed since the mid-1800s, but before that it cooled for more than five centuries. Cycles of warming and cooling have been part of Earth's natural *climate* history for millions of years. So what is the global warming debate about? It's about the proposition that human use of fossil fuels has contributed significantly to the past century's warming, and that expected future warming may have catastrophic global consequences. But hard evidence for this human contribution simply does not exist; the evidence we have is suggestive at best. Does that mean the human effects are not occurring? Not necessarily. But media coverage of global warming has been so alarmist that it fails to convey how flimsy the evidence really is. Most people don't realize that many strong statements about a human contribution to global warming are based more on politics than on science. Indeed, the *climate* change issue has become so highly politicized that its scientific and political aspects are now almost indistinguishable. The United Nations Intergovernmental Panel on *Climate* Change (IPCC), upon which governments everywhere have depended for the best scientific information, has been transformed from a bona fide effort in international scientific cooperation into what one of its leading participants terms "a hybrid scientific/political organization."

Yet apart from the overheated politics, *climate* change remains a fascinating and important scientific subject. *Climate* dynamics and *climate* history are extraordinarily complex, and despite intensive study for decades, scientists are not yet able to explain satisfactorily such basic phenomena as extreme weather events (hurricanes, tornadoes, droughts), El Niño variations, historical *climate* cycles, and trends of atmospheric temperatures. The scientific uncertainties about all these matters are great, and not surprisingly, competent scientists disagree in their interpretations of what is and is not known. In the current politicized atmosphere, however, legitimate scientific differences about *climate* change have been lost in the noise of politics.

For some, global warming has become the ultimate symbol of pessimism about the environmental future. Writer Bill McKibben, for example, says, "If we had to pick one problem to obsess about over the next 50 years, we'd do well to make it carbon dioxide." I believe that we'd be far wiser to obsess about poverty than about carbon dioxide.

Fossil fuels (coal, oil, and natural gas) are the major culprits of the global warming controversy and happen also to be the principal energy sources for both rich and poor countries. Governments of the industrial countries have generally accepted the position, promoted by the IPCC, that humankind's use of fossil fuels is a major contributor to global warming, and in 1997 they forged an international agreement (the Kyoto *Climate* Change Protocol) mandating that worldwide fossil fuel use be drastically reduced as a precaution against future warming. In contrast, the developing nations for the most part do not accept global warming as a high-priority issue and, as yet, are not subject to the Kyoto agreement. Thus, the affluent nations and the developing nations have set themselves on a collision course over environmental *policy* relating to fossil fuel use.

The debate about global warming focuses on carbon dioxide, a gas emitted into the atmosphere when fossil fuels are burned. Environmentalists generally label carbon dioxide as a pollutant; the Sierra Club, for example, in referring to carbon dioxide, states that "we are choking our planet in a cloud of this pollution." But to introduce the term pollution in this context is misleading because carbon dioxide is neither scientifically nor legally considered a pollutant. Though present in Earth's atmosphere in small amounts, carbon dioxide plays an essential role in maintaining life and as part of Earth's temperature control system.

Those who have had the pleasure of an elementary chemistry course will recall that carbon dioxide is one of the two main products of the combustion in air of any fossil fuel, the other being water. These products are generally emitted into the atmosphere, no matter whether the combustion takes place in power plants, household gas stoves and heaters, manufacturing facilities, automobiles, or other sources. The core scientific issue of the global warming debate is the extent to which atmospheric carbon dioxide from fossil fuel burning affects global *climate*.

When residing in the atmosphere, carbon dioxide and water vapor are called "greenhouse gases," so named because they trap some of Earth's heat in the same way that the glass canopy of a greenhouse prevents some of its internal heat from escaping, thereby warming the interior of the greenhouse. By this type of heating, greenhouse gases occurring naturally in the atmosphere perform a critical function. In fact, without greenhouse gases Earth would be too cold, all water on the planet would be frozen, and life as we know it would never have developed. In addition to its role in greenhouse warming, carbon dioxide is essential for plant physiology; without it, all plant life would die.

A number of greenhouse gases other than carbon dioxide and water vapor occur naturally in Earth's atmosphere and have been there for millennia. What's new is that during the industrial era, humankind's burning of fossil fuels has been adding carbon dioxide to the atmospheric mix of greenhouse gases over and above the amounts naturally present. The preindustrial level of 287 parts per million (ppm) of carbon dioxide in the atmosphere has increased almost 30 percent, to 367 ppm (as of 1998).

Few, if any, scientists question the measurements showing that atmospheric carbon dioxide has increased by almost a third. Nor do most scientists question that humans are the cause of most or all of the carbon dioxide increase. Yet the media continually point to these two facts as the major evidence that humans are causing the global warming Earth has recently experienced. The weak link in this argument is that empirical science has not established an unambiguous connection between the carbon dioxide increase and the observed global warming. The real scientific controversy about global warming is not about the presence of additional carbon dioxide in the atmosphere from human activities, which is well established, but about the extent to which that additional carbon dioxide affects *climate*, now or in the future.

Earth's *climate* is constantly changing from natural causes that, for the most part, are not understood. How are we to distinguish the human contribution, which may be very small, from the natural contribution, which may be small or large? Put another way, is the additional carbon dioxide humans are adding to the atmosphere likely to have a measurable effect on global temperature, which is in any case changing continually from natural causes? Or is the temperature effect from the additional carbon dioxide likely to be imperceptible, and therefore unimportant as a practical matter?

Global warming is not something that happened only recently. In Earth's long history, *climate* change is the rule rather than the exception, and studies of Earth's temperature record going back a million years clearly reveal a number of *climate* cycles--warming and cooling trends. Their causes are multiple--possibly including periodic changes in solar output and variations in Earth's tilt and orbit--but poorly understood. In recent times, Earth entered a warming period. From thermometer records, we know that the air at Earth's surface warmed about 0.6 Celsius over the period from the 1860s to the present. The observed warming, however, does not correlate well with the growth in fossil fuel use during that period. About half of the observed warming took place before 1940, though it was only after 1940 that the amounts of greenhouse gases produced by fossil fuel burning rose rapidly, as a result of the heavy industrial expansions of World War II and the postwar boom (80 percent of the carbon dioxide from human activities was added to the air after 1940).

Surprisingly, from about 1940 until about 1980, during a period of rapid increase in fossil fuel burning, global surface temperatures actually displayed a slight cooling trend rather than an acceleration of the warming trend that would have been expected from greenhouse gases. During the 1970s some scientists even became concerned about the possibility of a new ice age from an extended period of global cooling (a report of the U.S. National Academy of Sciences reflected that concern). Physicist Freeman Dyson notes that "the onset of the next ice age [would be] a far more severe catastrophe than anything associated with warming."

Earth's cooling trend did not continue beyond 1980, but neither has there been an unambiguous warming trend. Since 1980, precise temperature measurements have been made in Earth's atmosphere and on its surface, but the results do not agree. The surface air measurements indicate significant warming (0.25 to 0.4 Celsius), but the atmospheric measurements show very little, if any, warming.

Briefly, then, the record is this. From 1860 to 1940, Earth's surface warmed about 0.4 Celsius. Then Earth's surface cooled about 0.1 Celsius in the first four decades after 1940 and warmed about 0.3 Celsius in the next two. For those two most recent decades, temperature measurements of the atmosphere have also been available, and, while these measurements are subject to significant uncertainty, they indicate that the atmosphere's temperature has remained essentially unchanged. Thus, the actual temperature record does not support the claims widely found in environmental literature and the media that Earth has been steadily warming over the past century. (A new study that may shed more light on this question--one of a number sure to come--has been circulated but is being revised and has not yet been published.)

For the probable disparity between the surface and atmospheric temperature trends of the past 20 years, several explanations have been offered. The first is that large urban centers create artificial heating zones--"heat islands"--that can contribute to an increase of surface temperature (though one analysis concludes that the heat island effect is too small to explain the discrepancy fully). The second explanation is that soot and dust from volcanic eruptions may have contributed to cooling of the atmosphere by blocking the Sun's heat (though this cooling should have affected both surface and atmospheric temperatures). In the United States, despite the presence of large urban areas, surface cooling after 1930 far exceeded that of Earth as a whole, and the surface temperature has subsequently warmed only to the level of the 1930s.

It's frequently claimed that the recent increases in surface temperature are uniquely hazardous to Earth's ecosystems because of the rapidity with which they are occurring--more than 0.1 Celsius in a decade. That may be true, but some past *climate* changes were rapid as well. For example, around 14,700 years ago, temperatures in Greenland apparently jumped 5 Celsius in less than 20 years--almost three times the warming from greenhouse gases predicted to occur in this entire century by the most pessimistic scientists.

Whatever the current rate of surface warming, there is little justification for the view that Earth's *climate* should be unchanging, and that any *climate* change now occurring must have been caused by humans and should therefore be fixed by humans. In fact, as noted earlier, changing *climate* patterns and cycles have occurred throughout Earth's history. For millions of years, ice sheets regularly waxed and waned as global heating and cooling processes took place. During the most recent ice age, some 50,000 years ago, ice sheets covered much of North America, northern Europe, and northern Asia. About 12,000 years ago a warming trend began, signaling the start of an interglacial period that continues to this day. This warm period may have peaked 5,000 to 6,000 years ago, when global ice melting accelerated and global temperatures became higher than today's. Interglacial periods are thought to persist for about 10,000 years, so the next ice age may be coming soon--that is, in 500 to 1,000 years.

Within the current interglacial period, smaller cyclic patterns have emerged. In the most recent millennium, several cycles occurred during which Earth alternately warmed and cooled. There's evidence for an unusually warm period over at least parts of the globe from the end of the first millennium to about 1300. A mild *climate* in the Northern Hemisphere during those centuries probably facilitated the migration of Scandinavian peoples to Greenland and Iceland, as well as their first landing on the North American continent, just after 1000. The settlements in Greenland and Iceland thrived for several hundred years but eventually were abandoned when the *climate* turned colder, after about

1450. The cold period, which lasted until the late 1800s, is often called the Little Ice Age. Agricultural productivity fell, and the mass exodus to North America of many Europeans is attributed at least in part to catastrophic crop failures such as the potato famine in Ireland.

A plausible interpretation of most or all of the observed surface warming over the past century is that Earth is in the process of coming out of the Little Ice Age cold cycle that began 600 years ago. The current warming trend could last for centuries, until the expected arrival of the next ice age, or it could be punctuated by transient warm and cold periods, as were experienced in the recent millennium.

A great deal of global warming rhetoric gives the impression that science has established beyond doubt that the recent warming is mostly due to human activities. But that has not been established. Though human use of fossil fuels might contribute to global warming in the future, there's no hard scientific evidence that it is already doing so, and the difficulty of establishing a human contribution by empirical observation is formidable. One would need to detect a very small amount of warming caused by human activity in the presence of a much larger background of naturally occurring *climate* change--a search for the proverbial needle in a haystack.

Still, understanding *climate* change is by no means beyond science's reach, and research is proceeding in several complementary ways. Paleoclimatologists have been probing Earth's past climatic changes and are uncovering exciting new information about Earth's *climate* history going back thousands, and even millions, of years. This paleohistory will help eventually to produce a definitive picture of Earth's evolving *climate*, and help in turn to clarify the *climate* changes we're experiencing in our own era. But we are far from knowing enough to be able to predict what the future may hold for Earth's *climate*.

Mindful of the limited empirical knowledge about *climate*, some *climate* scientists have been attempting to understand possible future changes by using computer modeling techniques. By running several scenarios, the modelers obtain a set of theoretical projections of how global temperature might change in the future in response to assumed inputs, governed mainly by the levels of fossil fuel use. But like all computer modeling, even state-of-the-art *climate* modeling has significant limitations. For example, the current models cannot simulate the natural variability of *climate* over century long time periods. A further major shortcoming is that they project only gradual *climate* change, whereas the most serious impacts of *climate* change could come about from abrupt changes. (A simple analogy is to the abrupt formation of frost, causing leaf damage and plant death, when the ambient air temperature gradually dips below the freezing point.) Given the shortcomings, policymakers should exercise considerable caution in using current *climate* models as quantitative indicators of future global warming.

Scientists have long been aware that physical factors other than greenhouse gases can influence atmospheric temperature. Among the most important are aerosols--tiny particles (sulfates, black carbon, organic compounds, and so forth) introduced into the atmosphere by a variety of pollution sources, including automobiles and coal-burning electricity generators, as well as by natural sources such as sea spray and desert dust. Some aerosols, such as black carbon, normally contribute to heating of the atmosphere because they absorb the Sun's heat (though black carbon aerosols residing at high altitudes can actually cool Earth's surface because they block the Sun's rays from getting through to it). Other aerosols, composed of sulfates and organic compounds, cool the atmosphere because they reflect or scatter the Sun's rays away from Earth. Current evidence indicates that aerosols may be responsible for cooling effects at Earth's surface and warming effects in Earth's atmosphere. But the impacts of pollution on Earth's *climate* are very uncertain. The factors involved are difficult to simulate, but they must be included in computer models if the models are to be useful indicators of future *climate*. When *climate* models are finally able to incorporate the full complexity of pollution effects, especially from aerosols, the projected global temperature change could be either higher or lower than current projections, depending on the chemistry, altitude, and geographic region of the particular aerosols involved. Or, it could even be zero.

In addition to pollution, other physical factors that can influence surface and atmospheric temperature are methane (another greenhouse gas), dust from volcanic activity, and changes in cloud cover, ocean circulation patterns, air-sea interactions, and the Sun's energy output. "The forcings that drive long-term *climate* change," concludes James Hansen, one of the pioneers of *climate* change science, "are not known with an accuracy sufficient to define future *climate* change. Anthropogenic greenhouse gases, which are well measured, cause a strong positive forcing [warming]. But other, poorly measured, anthropogenic forcings, especially changes of atmospheric aerosols, clouds, and land-use patterns, cause a negative forcing that tends to offset greenhouse warming." And as if the physical factors were not challenging enough, the inherent complexity of the *climate* system will always be present to thwart attempts to predict future *climate*.

In view of *climate's* complexity and the limitations of today's *climate* simulations, one might expect that pronouncements as to human culpability for *climate* change would be made with considerable circumspection, especially pronouncements made in the name of the scientific community. So it was disturbing to many scientists that a summary report of the IPCC issued in 1996 contained the assertion that "the balance of evidence suggests a discernible *climate* change due to human activities." The latest IPCC report (2001) goes even further, claiming that "there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." But most of this evidence comes from new computer simulations and does not satisfactorily address either the disparity in the empirical temperature record between surface and atmosphere or the large uncertainties in the contributions of aerosols and other factors. A report issued by the National Academy of Sciences in 2001 says this about the model simulations:

Because of the large and still uncertain level of natural variability inherent in the *climate* record and the uncertainties in the time histories of the various forcing agents (and presumably aerosols), a causal linkage between the buildup of greenhouse gases in the atmosphere and the observed *climate* changes during the 20th century cannot be unequivocally established. The fact that the magnitude of the observed warming is large in comparison to natural variability as simulated in *climate* models is suggestive of such a linkage, but it does not constitute proof of one because the model simulations could be deficient in natural variability on the decadal to century time scale.

These IPCC reports have been adopted as the centerpiece of most current popularizations of global warming in the media and in the environmental literature, and their political impact has been enormous. The 1996 report was the principal basis for government *climate policy* in most industrial countries, including the United States. The IPCC advised in the report that drastic reductions in the burning of fossil fuels would be required to avoid a disastrous global temperature increase. That advice was the driving force behind the adoption in 1997 of the Kyoto protocol to reduce carbon dioxide emissions in the near future.

In its original form, the protocol had many flaws. First, it exempted developing countries, including China, India, and Brazil, from the emission cutbacks; such countries are increasingly dependent on fossil fuels, and their current greenhouse gas emissions already exceed those of the developed countries. Second, it mandated short-term reductions in fossil fuel use to reach the emission targets without regard to the costs of achieving those targets. Forced cutbacks in fossil fuel use could have severe economic consequences for industrial countries (the protocol would require the United States to cut back its fossil fuel combustion by over 30 percent to reach the targeted reduction of carbon dioxide emissions by 2010), and even greater consequences for poor countries should they ultimately agree to be included in the emissions targets. The costs of the cutbacks would have to be paid up front, whereas the assumed benefits would come only many decades later. Third, the fossil fuel cutbacks mandated by the protocol are too small to be effective--averting, by one estimate, only 0.06 Celsius of global warming by 2050.

The Kyoto protocol was signed in 1997 by many industrial countries, including the United States, but to have legal status, it must be ratified by nations that together account for 55 percent of global greenhouse gas emissions. As of June 2002, the protocol had been ratified by 73 countries, including Japan and all 15 nations of the European Union. These countries are responsible, in all, for only 36 percent of emissions, but the 55 percent requirement may be met by Russia's expected ratification. Nonetheless, the treaty is unlikely to have real force without ratification by the United States. The Bush administration opposes the treaty, on the grounds of its likely negative economic impact on America, and has thus far not sought Senate ratification. Even the Clinton administration did not seek ratification, despite its having signed the initial protocol, because it was aware that the U.S. Senate had unanimously adopted a resolution rejecting in principle any *climate* change treaty that does not include meaningful participation by developing countries.

With the United States retaining its lone dissent, 165 nations agreed in November 2001 to a modified version of Kyoto that would ease the task of reducing carbon dioxide emissions by allowing nations to trade their rights to emit carbon dioxide, and by giving nations credit for the expansion of forests and farmland, which soak up carbon dioxide from the atmosphere. A study by economist William Nordhaus in Science magazine (Nov. 9,2001) finds that a Kyoto treaty modified along these lines would incur substantial costs, bring little progress toward its objective, and, because of the huge fund transfers that would result from the practice of emissions trading, stir political disputes. Nordhaus concludes that participation in the treaty would have cost the United States some $2.3 trillion over the coming decades--more than twice the combined cost to all other participants. It does not require sympathy with overall U.S. *climate* change *policy* to understand the nation's reluctance to be so unequal a partner in the Kyoto enterprise.

Though the political controversy continues, the science has moved away from its earlier narrow focus on carbon dioxide as a predictor of global warming to an increasing realization that the world's future *climate* is likely to be determined by a changing mix of complex and countervailing factors, many of which are not under human control and all of which are insufficiently understood. But regardless of the causes, we do know that Earth's surface has warmed during the past century. Although we don't know the extent to which it will warm in the future, or whether it will warm at all, we can't help but ask a couple of critical questions: How much does global warming matter? What would be the consequences if the global average temperature did actually rise during the current century by, say, some 2 Celsius?

Some environmentalists have predicted dire consequences from the warming, including extremes of weather, the loss of agricultural productivity, a destructive rise in sea level, and the spread of diseases. Activists press for international commitments much stronger than the Kyoto protocol to reduce the combustion of fossil fuels, and they justify the measures as precautionary. Others counter that the social and economic impacts of forced reductions in fossil fuel use would be more serious than the effects of a temperature rise, which could be small, or even beneficial.

Although the debate over human impacts on *climate* probably won't be resolved for decades, a case can be made for adopting a less alarmist view of a warmer world. In any event, the warmer world is already here. In the past 2,500 years, global temperatures have varied by more than 3 Celsius, and some of the changes have been much more abrupt than the gradual changes projected by the IPCC. During all of recorded history, humans have survived and prospered in *climate* zones far more different from one another than those that might result from the changes in global temperatures now being discussed.

Those who predict agricultural losses from a warmer *climate* have most likely got it backwards. Warm periods have historically benefited the development of civilization, and cold periods have been detrimental. For example, the Medieval Warm Period, from about 900 to 1300, facilitated the Viking settlement of Iceland and Greenland, whereas the subsequent Little Ice Age led to crop failures, famines, and disease. Even a small temperature increase brings a longer and more frost-free growing season--an advantage for many farmers, especially those in large, cold countries such as Russia and Canada. Agronomists know that the enrichment of atmospheric carbon dioxide stimulates plant growth and development in greenhouses; such enrichment at the global level might be expected to increase vegetative and biological productivity and water-use efficiency. Studies of the issue from an economic perspective have reached the same conclusion: that moderate global warming would most likely produce net economic benefits, especially for the agriculture and forestry sectors. Of course, such projections are subject to great uncertainty and cannot exclude the possibility that unexpected negative impacts would occur.

As for the concern that warmer temperatures would spread insect-borne diseases such as malaria, dengue fever, and yellow fever, there's no solid evidence to support it. Although the spread of disease is a complex matter, the main carriers of these diseases--which were common in North America, western Europe, and Russia during the 19th century, when the world was colder than it is today--are most likely humans traveling the globe and insects traveling with people and goods. The strongest ally against future disease is surely not a cold *climate* but concerted improvement in regional insect control, water quality, and public health. As poverty recedes and people's living conditions improve in the developing world, the level of disease, and its spread, can be expected to decrease. Paul Reiter, a specialist in insect-borne diseases, puts it this way:

Insect-borne diseases are not diseases of *climate* but of poverty. Whatever the *climate*, developing countries will remain at risk until they acquire window screens, air conditioning, modern medicine, and other amenities most Americans take for granted. As a matter of social *policy*, the best precaution is to improve living standards in general and health infrastructures in particular.

One of the direst (and most highly publicized) predictions of global warming theorists is that greenhouse gas warming will cause sea level to rise and that, as a result, many oceanic islands and lowland areas, such as Bangladesh, may be submerged. But in fact, sea level--which once was low enough to expose a land bridge between Siberia and Alaska--is rising now, and has been rising for thousands of years. Recent analyses suggest that sea level rose at a rate of about one to two centimeters per century (0.4 to 0.8 inch) over the past 3,000 years. Some studies have interpreted direct sea-level measurements made throughout the 20th century to show that the level is now rising at a much faster rate, about 10 to 25 centimeters per century (4 to 10 inches), but other studies conclude that the rate is much lower than that. To whatever extent sea-level rise may have accelerated, the change is thought to have taken place before the period of industrialization.

Before considering whether the ongoing sea-level rise has anything to do with human use of fossil fuels, let's examine what science has to say about how global temperature change may relate to sea-level change. The matter is more complicated than it first appears. Water expands as it warms, which would contribute to rising sea level. But warming increases the evaporation of ocean water, which could increase the snowfall on the Arctic and Antarctic ice sheets, remove water from the ocean, and lower sea level. The relative importance of these two factors is not known.

We do know from studies of the West Antarctic Ice Sheet that it has been melting continuously since the last great ice age, about 20,000 years ago, and that sea level has been rising ever since. Continued melting of the ice sheet until the next ice age may be inevitable, in which case sea level would rise by 15 to 18 feet when the sheet was completely melted. Other mechanisms have been suggested for natural sea-level rise, including tectonic changes in the shape of the ocean basins. The theoretical computer *climate* models attribute most of the sea-level rise to thermal expansion of the oceans, and thus they predict that further global temperature increase (presumably from human activities) will accelerate the sea-level rise. But because these models cannot deal adequately with the totality of the natural phenomena involved, their predictions about sea-level rise should be viewed skeptically.

The natural causes of sea-level rise are part of Earth's evolution. They have nothing to do with human activities, and there's nothing that humans can do about them. Civilization has always adjusted to such changes, just as it has adjusted to earthquakes and other natural phenomena. This is not to say that adjusting to natural changes is not sometimes painful, but if there's nothing we can do about certain natural phenomena, we do adjust to them, however painfully. Sea-level rise is, most likely, one of those phenomena over which humans have no control.

Some environmentalists claim that weather-related natural disasters have been increasing in frequency and severity, presumably as a result of human-caused global warming, but the record does not support their claims. On the contrary, several recent statistical studies have found that natural disasters--hurricanes, typhoons, tropical storms, floods, blizzards, wild tires, heat waves, and earthquakes--are not on the increase. The costs of losses natural disasters are indeed rising, to the dismay of insurance companies and government emergency agencies, but that's because people in affluent societies construct expensive properties in places vulnerable to natural hazards, as coastlines, steep hills, and forested areas.

Because society has choices, we must ask what the likely effects would be, on the one hand, if people decided to adjust to *climate* change, regardless of its causes, and, on the other, if governments implemented drastic *policies* to attempt to lessen the presumed human contribution to the change. From an economic perspective at least, adjusting to the change would almost surely come out ahead. Several analyses have projected that the overall cost of the worst-case consequences of warming would be no more than about a two percent reduction in world output. Given that average per capita income will probably quadruple during the next century, the potential loss seems small indeed. A recent economic study emphasizing adaptation to *climate* change indicates that in the market economy of the United States the overall impacts of modest global warming are even likely to be beneficial rather than damaging, though the amount of net benefit would be small, about 0.2 percent of the economy. (We need always to keep in mind the statistical uncertainties inherent in such analyses; there are small probabilities that the benefits or costs could turn out to be much greater than or much less than the most probable outcomes.)

In contrast, the economic costs of governmental actions restricting the use of fossil fuels could be large indeed, as suggested by the Nordhaus study cited earlier on the costs of compliance with the Kyoto treaty. One U.S. government study proposed that a cost-effective way of bringing about fossil fuel reductions would be a combination of carbon taxes and international trading in emissions rights. Emissions rights trading was, in fact, included in the modified Kyoto agreement. But such a trading scheme would result in huge income transfers, as rich nations paid poor nations for emissions quotas that the latter would probably not have used anyway--and it's not reasonable to assume that rich nations would be willing to do this.

Taking into account the large uncertainties in estimating the future growth of the world economy, and the corresponding growth in fossil fuel use, one group of economists puts the costs of greenhouse gas reduction in the neighborhood of one percent of world output, while another group puts it at around five percent of output. The costs would be considerably higher if large reductions were forced upon the global economy over a short time period, or if, as is likely, the most economically efficient schemes to bring about the reductions were not actually employed. Political economists Henry Jacoby, Ronald Prinn, and Richard Schmalensee put the matter bluntly: "It will be nearly impossible to slow *climate* warming appreciably without condemning much of the world to poverty, unless energy sources that emit little or no carbon dioxide become competitive with conventional fossil fuels."

Some global warming has been under way for more than a century, at least partly from natural causes, and the world has been adjusting to it as it did to earlier *climate* changes. If human activity is finally judged to be adding to the natural warming, the amount of the addition is probably small, and society can adjust to that as well, at relatively low cost or even net benefit. But the industrial nations are not likely to carry out inefficient, Kyoto-type mandated reductions in fossil fuel use on the basis of so incomplete a scientific foundation as currently exists. The costs of so doing could well exceed the potential benefits. Far more effective would be *policies* and actions by the industrial countries to accelerate the development, in the near term, of technologies that utilize fossil fuels (and all resources) more efficiently and, in the longer term, of technologies that do not require the use of fossil fuels.

If *climate* science is to have any credibility in the future, its pursuit must be kept separate from global politics. The affluent nations should support research programs that improve the theoretical understanding of *climate* change, build an empirical database about factors that influence long-term *climate* change, and increase our understanding of short-term weather dynamics. Such research is fundamental to the greenhouse gas issue. But its rewards may be greater still, for it will also improve our ability to cope with extreme weather events such as hurricanes, tornadoes, and floods, whatever their causes.

GRAPH: Wide fluctuations in surface temperatures have been the norm in Earth's history. These estimates are derived from oxygen-isotope ratios in fossilized plankton from the ocean floor.

GRAPH: Scientists know that mean global surface air temperatures have been rising for a century, but they don't know for certain why--nor why temperatures fell between 1940 and 1980.

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