An Experiment to Accelerate Scientific Progress

by

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I. Background

Several months ago Freeman Dyson discussed the science of climate change and policy options in The New York Review of Books (Attachment 1).[2] One visionary possibility is to design plants that will biologically sequester atmospheric carbon dioxide: such breakthroughs can help to mitigate the long-term effects of human activity on climate change. Dyson (who calls them "carbon-eating trees") writes:

> "Carbon-eating trees could convert most of the carbon that they absorb from the atmosphere into some chemically stable form and bury it underground. Or they could convert the carbon into liquid fuels and other useful chemicals. Biotechnology is enormously powerful, capable of burying or transforming any molecule of carbon dioxide that comes into its grasp. . . . If one quarter of the world's forests were replanted with carbon-eating varieties of the same species . . . the carbon dioxide in the atmosphere would be reduced by half in about fifty years."[3]

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[2] Freeman Dyson, "The Question of Global Warming," The New York Review of Books, 55:10 (June 12, 2008). Online at www.nybooks.com. See also the letters and exchanges in issues of 7/17, 9/25, and 10/9, ibid. Page numbers refer to the pages in the appended copy.

[3] Op cit., p. 9.

Dyson estimates that it may require 20-50 years for the necessary scientific breakthroughs. But could they be achieved more quickly?

II. Proposal

I believe that the capacities of the emerging global Internet can be used boldly to build large-scale collaboration systems and accelerate the creative process to solve this problem. This paper suggests an experiment to test this possibility.[4]

- Specifically, I suggest that the World Academy of Art and Science play a leading role to identify partners and convene an international working group to plan, raise funds for, and organize such an experiment. The goal will be to create and test the best design for Internet-based acceleration to address these urgent challenges and achieve the required breakthroughs quickly.

One possibility is that the working group could assemble a professional production team and design a series of three "Inventions Wanted . . ." global colloquia (for an audience of scientists in all countries and fields). These high-visibility colloquia (e.g., to be scheduled in 2009 on the first Tuesday of the month for three months) will focus attention and convey scientific briefings about the possibility that Dyson has discussed; define relevant questions, foster fresh thinking, and accelerate the creative process; and enroll wider participation in the search for breakthroughs. The working group also will

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[4] The late Marshall McLuhan observed that the revolutionary potential of new communication technologies is greater than it initially appears because early applications merely use new technology for established behavior. Thus, the early use of the motion picture camera was to place the camera at a fixed position and film stage plays. Similarly, the use of Internet multimedia still focuses on putting scientific lectures and conferences online, to be viewed by audiences as if they were attending standard lectures and conferences in physical reality. A bold prototype to accelerate the biological sequestration of atmospheric carbon-dioxide can help us to learn lessons about the design of next-generation applications.

develop a Website with online resources and capabilities to support a fast, cross-boundary, creative process.[5]

For example:[6] [7]

<u>Session 1</u> will brief the world's scientists about Dyson's analysis and the importance of the challenge. It might include a state-of-the-art discussion of what we know about photosynthesis and the plant biology involved in capturing, storing, changing, and releasing atmospheric carbon-dioxide and/or analogous processes.[8]

<u>Session 2</u> of "Inventions Wanted . . . " might include an expert briefing about the diversity of known land and ocean plants with desirable properties and our relevant genetic knowledge about these species. [I.e., a good strategy might be to identify plants that already sequester carbon-dioxide permanently (if any exist) and/or that are good performers at other sub-tasks (e.g., acquiring large quantities of atmospheric carbon-

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[5] A site with interesting ideas for creative scientific uses of Internet technology is http://www. scivee.tv developed by the San Diego Supercomputing Center, NSF, and the Public Library of Science. See the discussion by the co-founder, Phil Bourne, at http://www.scivee.tv/ scivee_overview.

[6] I am suggesting this outline for the purpose of getting discussion underway - I am not a biologist. The best design of discussions for a global scientific audience to stimulate the creative process will be part of the challenge for the working group and its production team.

[7] One of the temptations may be to simplify discussions to reach a wider audience. Such programs might *evolve* from these brownbags (e.g., in the US, the NOVA series on the Public Broadcast System; or a Discovery Channel program for high school science students) but it would be a mistake to water-down these professional colloquia.

[8] It may be helpful to recognize several environmentally-relevant breakthroughs that already have been achieved. For example, I understand that micro-organisms have been developed that can live happily underground in coal mines, eat coal, and convert it to natural gas.

dioxide)].[9] Leading current researchers might describe their strategies, where they are stuck, and where breakthroughs, additional researchers, and fresh ideas would help.[10]

Session 3's design would be an open-ended challenge to the planners. It will use feedback and discussion from the two original sessions to fashion and support the creative process on a global scale. . . Session 3 may discover that the most important contributions and catalysts for the road ahead are unexpected and that the fast, cross-breeding, possibilities of the Internet are especially useful to elicit these interdisciplinary and unexpected connections.[11] [12]

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[9] I am indebted to a panelist at a session organized by Pushpa Bhargava at the recent WAAS meeting for this suggestion. He thought that engineering new plants that can survive in natural settings will be more difficult that enhancement of attractive properties that exist in known plants,.

[10] Key papers, lists of sources of specimen plants, and other resources could be part of the Website. While the online discussions would be focused for research scientists, the supporting material could recognize a cross-generational engagement in scientific problem-solving, with additional material that could be used by secondary school, undergraduate, and graduate students who become interested in these challenges. Would there be useful experiments or observations that smart high school students, in many countries, could undertake?

[11] For example: Session 3 might include a panel of (known) brilliant scientists who could help to think aloud about the swirl of ideas and creative possibilities suggested by the world's viewing scientists. (In addition to benefits to the future of the planet, there may be many fortunes to be made if breakthroughs are possible and many of the world's forests are to be replanted. If the "Inventions Wanted . . ." panel also included scientists with passionate interests and deep corporate pockets - e.g., Craig Venter - this may add a touch of keen interest to the project.)

[12] There are concerns about whether scientists will divulge their best ideas in these public (global) arenas. However this is a standard issue in all scientific conferences and there are well-established norms for trading partial information (and later collegial speculating about what is not being disclosed). Also these global discussions will be highly attractive opportunities for participation: we can anticipate that they will be watched closely by venture capitalists and for-profit companies. Thus, creative scientists in many countries can

III. Learning Lessons

This prototype may be a spectacular success. If so, it may be possible to identify similar challenges and funding for additional projects. (For example, it might be possible to survey R&D-oriented industries and secure their financial support for global brownbag projects concerning environment- and energy-related breakthroughs for the future of their businesses - photovoltaics, fuel cells, battery design, reinventing the light bulb, applications of nano- technology to materials science to produce light, super-strong automobiles, etc.) Located eventually at a good institutional home, an "Inventions Wanted . . . " series could become a program that no scientist (or science-oriented undergraduate or graduate student) would miss.

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mention new ideas and use the opportunity, in effect, to advertise for consultantships and research support for their labs. Similarly, there will be a public and permanent record of discussions (before a global audience) that will establish scientific priority. This will create a clear historical record showing which scientist was the first to suggest a new line of investigation, etc. Scientists also can enroll collaborators, worldwide, to pursue their ideas.

Attachment 1

[from The New York Review of Books. Volume 55, Number 10. June 12, 2008.]

The Question of Global Warming

By Freeman Dyson

A Question of Balance: Weighing the Options on Global Warming Policies
by William Nordhaus
Yale University Press, 234 pp., $28.00

Global Warming: Looking Beyond Kyoto
edited by Ernesto Zedillo
Yale Center for the Study of Globalization/Brookings Institution Press, 237 pp., $26.95 (paper)

I begin this review with a prologue, describing the measurements that transformed global warming from a vague theoretical speculation into a precise observational science.

There is a famous graph showing the fraction of carbon dioxide in the atmosphere as it varies month by month and year by year (see the graph). It gives us our firmest and most accurate evidence of effects of human activities on our global environment. The graph is generally known as the Keeling graph because it summarizes the lifework of Charles David Keeling, a professor at the Scripps Institution of Oceanography in La Jolla, California. Keeling measured the carbon dioxide abundance in the atmosphere for forty-seven years, from 1958 until his death in 2005. He designed and built the instruments that made accurate measurements possible. He began making his measurements near the summit of the dormant volcano Mauna Loa on the big island of Hawaii.

He chose this place for his observatory because the ambient air is far from any continent and is uncontaminated by local human activities or vegetation. The measurements have continued after Keeling's death, and show an unbroken record of rising carbon dioxide abundance extending over fifty years. The graph has two obvious and conspicuous features. First, a steady increase of carbon dioxide with time, beginning at 315 parts per million in 1958 and reaching 385 parts per million in 2008. Second, a regular wiggle showing a yearly cycle of growth and decline of carbon dioxide levels. The maximum happens each year in the Northern Hemisphere spring, the minimum in the Northern Hemisphere fall. The difference between maximum and minimum each year is about six parts per million.

Keeling was a meticulous observer. The accuracy of his measurements has never been challenged, and many other observers have confirmed his results. In the 1970s he extended his observations from Mauna Loa, at latitude 20 north, to eight other stations at various latitudes, from the South Pole at latitude 90 south to Point Barrow on the Arctic coast of Alaska at latitude 71 north. At every latitude there is the same steady growth of carbon dioxide levels, but the size of the annual wiggle varies strongly with latitude. The wiggle is largest at Point Barrow where the difference between maximum and minimum is about fifteen parts per million. At Kerguelen, a Pacific island at latitude 29 south, the wiggle vanishes. At the South Pole the difference between maximum and minimum is about two parts per million, with the maximum in Southern Hemisphere spring.

The only plausible explanation of the annual wiggle and its variation with latitude is that it is due to the seasonal growth and decay of annual vegetation, especially deciduous forests, in temperate latitudes north and south. The asymmetry of the wiggle between north and south is caused by the fact that the Northern Hemisphere has most of the land area and most of the deciduous forests. The wiggle is giving us a direct measurement of the quantity of carbon that is absorbed from the atmosphere each summer north and south by growing vegetation, and returned each winter to the atmosphere by dying and decaying vegetation.

The quantity is large, as we see directly from the Point Barrow measurements. The wiggle at Point Barrow shows that the net growth of vegetation in the Northern Hemisphere summer absorbs about 4 percent of the total carbon dioxide in the high-latitude atmosphere each year. The total absorption must be larger than the net growth, because the vegetation continues to respire during the summer, and the net growth is equal to total absorption minus respiration. The tropical forests at low latitudes are also absorbing and respiring a large quantity of carbon dioxide, which does not vary much with the season and does not contribute much to the annual wiggle.

When we put together the evidence from the wiggles and the distribution of vegetation over the earth, it turns out that about 8 percent of the carbon dioxide in the atmosphere is absorbed by vegetation and returned to the atmosphere every year. This means that the average lifetime of a molecule of carbon dioxide in the atmosphere, before it is captured by vegetation and afterward released, is about twelve years. This fact, that the exchange of carbon between atmosphere and vegetation is rapid, is of fundamental importance to the long-range future of global warming, as will become clear in what follows. Neither of the books under review mentions it.

1.

William Nordhaus is a professional economist, and his book <u>A Question of Balance: Weighing the Options on Global Warming Policies</u> describes the global-warming problem as an economist sees it. He is not concerned with the science of global warming or with the detailed estimation of the damage that it may do. He assumes that the science and the damage are specified, and he compares the effectiveness of various policies for the allocation of economic resources in response. His conclusions are largely independent of scientific details. He calculates aggregated expenditures and costs and gains. Everything is calculated by running a single computer model which he calls DICE, an acronym for

Dynamic Integrated Model of Climate and the Economy.

Each run of DICE takes as input a particular policy for allocating expenditures year by year. The allocated resources are spent on subsidizing costly technologies—for example, deep underground sequestration of carbon dioxide produced in power stations—that reduce emissions of carbon dioxide, or placing a tax on activities that produce carbon emissions. The climate model part of DICE calculates the effect of the reduced emissions in reducing damage. The output of DICE then tells us the resulting gains and losses of the world economy year by year. Each run begins at the year 2005 and ends either at 2105 or 2205, giving a picture of the effects of a particular policy over the next one or two hundred years.

The practical unit of economic resources is a trillion inflation-adjusted dollars. An inflation-adjusted dollar means a sum of money, at any future time, with the same purchasing power as a real dollar in 2005. In the following discussion, the word "dollar" will always mean an inflation-adjusted dollar, with a purchasing power that does not vary with time. The difference in outcome between one policy and another is typically several trillion dollars, comparable with the cost of the war in Iraq. This is a game played for high stakes.

Nordhaus's book is not for the casual reader. It is full of graphs and tables of numbers, with an occasional equation to show how the numbers are related. The graphs and tables show how the world economy reacts to the various policy options. To understand these graphs and tables, readers should be familiar with financial statements and compound interest, but they do not need to be experts in economic theory. Anyone who knows enough mathematics to balance a checkbook or complete an income tax return should be able to understand the numbers.

For the benefit of those who are mathematically illiterate or uninterested in numerical details, Nordhaus has put a nonmathematical chapter at the beginning with the title "Summary for the Concerned Citizen." This first chapter contains an admirably clear summary of his results and their practical consequences, digested so as to be read by busy politicians and ordinary people who may vote the politicians into office. He believes that the most important concern of any policy that aims to address climate change should be how to set the most efficient "carbon price," which he defines as "the market price or penalty that would be paid by those who use fossil fuels and thereby generate CO2 emissions." He writes:

Whether someone is serious about tackling the global-warming problem can be readily gauged by listening to what he or she says about the carbon price. Suppose you hear a public figure who speaks eloquently of the perils of global warming and proposes that the nation should move urgently to slow climate change. Suppose that person proposes regulating the fuel efficiency of cars, or requiring high-efficiency lightbulbs, or subsidizing ethanol, or providing research support for solar power—but nowhere does the proposal raise the price of carbon. You should conclude that the proposal is not really serious and does not recognize the central economic message about how to slow climate change. To a first approximation, raising the price of carbon is a necessary and sufficient step for tackling global warming. The rest is at best rhetoric and may actually be harmful in inducing economic inefficiencies.

If this chapter were widely read, the public understanding of global warming and possible responses to it would be greatly improved.

Nordhaus examines five kinds of global-warming policy, with many runs of DICE for each kind. The first kind is business-as-usual, with no restriction of carbon dioxide emissions—in which case, he estimates damages to the environment amounting to some $23 trillion in current dollars by the year 2100. The second kind is the "optimal policy," judged by Nordhaus to be the most cost-effective, with a worldwide tax on carbon emissions adjusted each year to give the maximum aggregate economic gain as calculated by DICE. The third kind is the Kyoto Protocol, in operation since 2005 with 175 participating countries, imposing fixed limits to the emissions of economically developed countries only. Nordhaus tests various versions of the Kyoto Protocol, with or without the participation of the United States.

The fourth kind of policy is labeled "ambitious" proposals, with two versions which Nordhaus calls "Stern" and "Gore." "Stern" is the policy advocated by Sir Nicholas Stern in the Stern Review, an economic analysis of global-warming policy sponsored by the British government.[*] "Stern" imposes draconian limits on emissions, similar to the Kyoto limits but much stronger. "Gore" is a policy advocated by Al Gore, with emissions reduced drastically but gradually, the reductions reaching 90 percent of current levels before the year 2050. The fifth and last kind is called "low-cost backstop," a policy based on a hypothetical low-cost technology for removing carbon dioxide from the atmosphere, or for producing energy without carbon dioxide emission, assuming that such a technology will become available at some specified future date. According to Nordhaus, this technology might include "low-cost solar power, geothermal energy, some nonintrusive climatic engineering, or genetically engineered carbon-eating trees."

Since each policy put through DICE is allowed to run for one or two hundred years, its economic effectiveness must be measured by an aggregated sum of gains and losses over the whole duration of the run. The most crucial question facing the policymaker is then how to compare present-day gains and losses with gains and losses a hundred years in the future. That is why Nordhaus chose "A Question of Balance" for his title. If we can save M dollars of damage caused by climate change in the year 2110 by spending one dollar on reducing emissions in the year 2010, how large must M be to make the spending worthwhile? Or, as economists might put it, how much can future losses from climate change be diminished or "discounted" by money invested in reducing emissions now?

The conventional answer given by economists to this question is to say that M must be larger than the expected return in 2110 if the 2010 dollar were invested in the world economy for a hundred years at an average rate of compound interest. For example, the value of one dollar invested at an average interest rate of 4 percent for a period of one hundred years would be fifty-four dollars; this would be the future value of one dollar in one hundred years' time. Therefore, for every dollar spent now on a particular strategy to fight global warming, the investment must reduce the damage caused by warming by an amount that exceeds fifty-four dollars in one hundred years' time to accrue a positive economic benefit to society. If a strategy of a tax on carbon emissions results in a return of only forty-four dollars per dollar invested, the benefits of adopting the strategy will be outweighed by the costs of paying for it. But if the strategy produces a return of sixty-four dollars per dollar invested, the advantages are clear. The question then is how well different strategies of dealing with global warming succeed in producing long-term benefits that outweigh their present costs. The aggregation of gains and losses over time should be calculated with the remote future heavily discounted.

The choice of discount rate for the future is the most important decision for anyone making long-range plans. The discount rate is the assumed annual percentage loss in present value of a future dollar as it moves further into the future. The DICE program allows the discount rate to be chosen arbitrarily, but Nordhaus displays the results only for a discount rate of 4 percent. Here he is following the conventional wisdom of economists. Four percent is a conservative number, based on an average of past experience in good and bad times. Nordhaus is basing his judgment on the assumption that the next hundred years will bring to the world economy a mixture of stagnation and prosperity, with overall average growth continuing at the same rate that we have experienced during the twentieth century. Future costs are discounted because the future world will be richer and better able to afford them. Future benefits are discounted because they will be a diminishing fraction of future wealth.

When the future costs and benefits are discounted at a rate of 4 percent per year, the aggregated costs and benefits of a climate policy over the entire future are finite. The costs and benefits beyond a hundred years make little difference to the calculated aggregate. Nordhaus therefore takes the aggregate benefit-minus-cost over the entire future as a measure of the net value of the policy. He uses this single number, calculated with the DICE model of the world economy, as a figure of merit to compare one policy with another. To represent the value of a policy by a single number is a gross oversimplification of the real world, but it helps to concentrate our attention on the most important differences between policies.

Here are the net values of the various policies as calculated by the DICE model. The values are calculated as differences from the business-as-usual model, without any emission controls. A plus value means that the policy is better than business-as-usual, with the reduction of damage due to climate change exceeding the cost of controls. A minus value means that the policy is worse than business-as-usual, with costs exceeding the reduction of damage. The unit of value is $1 trillion, and the values are specified to the nearest trillion. The net value of the optimal program, a global carbon tax increasing gradually with time, is plus three—that is, a benefit of some $3 trillion. The Kyoto Protocol has a value of plus one with US participation, zero without US participation. The "Stern" policy has a value of minus fifteen, the "Gore" policy minus twenty-one, and "low-cost backstop" plus seventeen.

What do these numbers mean? $1 trillion is a difficult unit to visualize. It is easier to think of it as $3,000 for every man, woman, and child in the US population. It is comparable to the annual gross domestic product of India or Brazil. A gain or loss of $1 trillion would be a noticeable but not overwhelming perturbation of the world economy. A gain or loss of $10 trillion would be a major perturbation with unpredictable consequences.

The main conclusion of the Nordhaus analysis is that the ambitious proposals, "Stern" and "Gore," are disastrously expensive, the "low-cost backstop" is enormously advantageous if it can be achieved, and the other policies including business-as-usual and Kyoto are only moderately worse than the optimal policy. The practical consequence for global-warming policy is that we should pursue the following objectives in order of priority. (1) Avoid the ambitious proposals. (2) Develop the science and technology for a low-cost backstop. (3) Negotiate an international treaty coming as close as possible to the optimal policy, in case the low-cost backstop fails. (4) Avoid an international treaty making the Kyoto Protocol policy permanent. These objectives are valid for economic reasons, independent of the scientific details of global warming.

There is a fundamental difference of philosophy between Nordhaus and Sir Nicholas Stern. Chapter 9 of Nordhaus's book explains the difference, and explains why Stern advocates a policy that Nordhaus considers disastrous. Stern rejects the idea of discounting future costs and benefits when they are compared with present costs and benefits. Nordhaus, following the normal practice of economists and business executives, considers discounting to be necessary for reaching any reasonable balance between present and future. In Stern's view, discounting is unethical because it discriminates between present and future generations. That is, Stern believes that discounting imposes excessive burdens on future generations. In Nordhaus's view, discounting is fair because a dollar saved by the present generation becomes fifty-four dollars to be spent by our descendants a hundred years later.

The practical consequence of the Stern policy would be to slow down the economic growth of China now in order to reduce damage from climate change a hundred years later. Several generations of Chinese citizens would be impoverished to make their descendants only slightly richer. According to Nordhaus, the slowing-down of growth would in the end be far more costly to China than the climatic damage. About the much-discussed possibility of catastrophic effects before the end of the century from rising sea levels, he says only that "climate change is unlikely to be catastrophic in the near term, but it has the potential for serious damages in the long run." The Chinese government firmly rejects the Stern philosophy, while the British government enthusiastically embraces it. The Stern Review, according to Nordhaus, "takes the lofty vantage point of the world social planner, perhaps stoking the dying embers of the British Empire."

2.

The main deficiency of Nordhaus's book is that he does not discuss the details of the "low-cost backstop" that might provide a climate policy vastly more profitable than his optimum policy. He avoids this subject because he is an economist and not a scientist. He does not wish to question the pronouncements of the Intergovernmental Panel on Climate Change, a group of hundreds of scientists officially appointed by the United Nations to give scientific advice to governments. The Intergovernmental Panel considers the science of climate change to be settled, and does not believe in low-cost backstops. Concerning the possible candidates for a low-cost backstop technology he mentions in the sentence I previously quoted—for example, "low-cost solar power"—Nordhaus has little to say. He writes that "no such technology presently exists, and we can only speculate on it." The "low-cost backstop" policy is displayed in his tables as an abstract possibility without any details. It is nowhere emphasized as a practical solution to the problem of climate change.

At this point I return to the Keeling graph, which demonstrates the strong coupling between atmosphere and plants. The wiggles in the graph show us that every carbon dioxide molecule in the atmosphere is incorporated in a plant within a time of the order of twelve years. Therefore, if we can control what the plants do with the carbon, the fate of the carbon in the atmosphere is in our hands. That is what Nordhaus meant when he mentioned "genetically engineered carbon-eating trees" as a low-cost backstop to global warming. The science and technology of genetic engineering are not yet ripe for large-scale use. We do not understand the language of the genome well enough to read and write it fluently. But the science is advancing rapidly, and the technology of reading and writing genomes is advancing even more rapidly. I consider it likely that we shall have "genetically engineered carbon-eating trees" within twenty years, and almost certainly within fifty years.

Carbon-eating trees could convert most of the carbon that they absorb from the atmosphere into some chemically stable form and bury it underground. Or they could convert the carbon into liquid fuels and other useful chemicals. Biotechnology is enormously powerful, capable of burying or transforming any molecule of carbon dioxide that comes into its grasp. Keeling's wiggles prove that a big fraction of the carbon dioxide in the atmosphere comes within the grasp of biotechnology every decade. If one quarter of the world's forests were replanted with carbon-eating varieties of the same species, the forests would be preserved as ecological resources and as habitats for wildlife, and the carbon dioxide in the atmosphere would be reduced by half in about fifty years.

It is likely that biotechnology will dominate our lives and our economic activities during the second half of the twenty-first century, just as computer technology dominated our lives and our economy during the second half of the twentieth. Biotechnology could be a great equalizer, spreading wealth over the world wherever there is land and air and water and sunlight. This has nothing to do with the misguided efforts that are now being made to reduce carbon emissions by growing corn and converting it into ethanol fuel. The ethanol program fails to reduce emissions and incidentally hurts poor people all over the world by raising the price of food. After we have mastered biotechnology, the rules of the climate game will be radically changed. In a world economy based on biotechnology, some low-cost and environmentally benign backstop to carbon emissions is likely to become a reality.

Global Warming: Looking Beyond Kyoto is the record of a conference held at the Yale Center for the Study of Globalization in 2005. It is edited by Ernesto Zedillo, the head of the Yale Center, who served as president of Mexico from 1994 to 2000 and was chairman of the conference. The book consists of an introduction by Zedillo and fourteen chapters contributed by speakers at the conference. Among the speakers was William Nordhaus, contributing "Economic Analyses of the Kyoto Protocol: Is There Life After Kyoto?," a sharper criticism of the Kyoto Protocol than we find in his own book.

The Zedillo book covers a much wider range of topics and opinions than the Nordhaus book, and is addressed to a wider circle of readers. It includes "Is the Global Warming Alarm Founded on Fact?," by Richard Lindzen, professor of atmospheric sciences at MIT, answering that question with a resounding no. Lindzen does not deny the existence of global warming, but considers the predictions of its harmful effects to be grossly exaggerated. He writes,

> Actual observations suggest that the sensitivity of the real climate is much less than that found in computer models whose sensitivity depends on processes that are clearly misrepresented.

Answering Lindzen in the next chapter, "Anthropogenic Climate Change: Revisiting the Facts," is Stefan Rahmstorf, professor of physics of the oceans at Potsdam University in Germany. Rahmstorf sums up his opinion of Lindzen's arguments in one sentence: "All this seems completely out of touch with the world of climate science as I know it and, to be frank, simply ludicrous." These two chapters give the reader a sad picture of climate science. Rahmstorf represents the majority of scientists who believe fervently that global warming is a grave danger. Lindzen represents the small minority who are skeptical. Their conversation is a dialogue of the deaf. The majority responds to the minority with open contempt.

In the history of science it has often happened that the majority was wrong and refused to listen to a minority that later turned out to be right. It may—or may not—be that the present is such a time. The great virtue of Nordhaus's economic analysis is that it remains valid whether the majority view is right or wrong. Nordhaus's optimum policy takes both possibilities into account. Zedillo in his introduction summarizes the arguments of each contributor in turn. He maintains the neutrality appropriate to a conference chairman, and gives equal space to Lindzen and to Rahmstorf. He betrays his own opinion only in a single sentence with a short parenthesis: "Climate change may not be the world's most pressing problem (as I am convinced it is not), but it could still prove to be the most complex challenge the world has ever faced."

The last five chapters of the Zedillo book are by writers from five of the countries most concerned with the politics of global warming: Russia, Britain, Canada, India, and China. Each of the five authors has been responsible for giving technical advice to a government, and each of them gives us a statement of that government's policy. Howard Dalton, spokesman for the British government, is the most dogmatic. His final paragraph begins:

> It is the firm view of the United Kingdom that climate change constitutes a major threat to the environment and human society, that urgent action is needed now across the world to avert that threat, and that the developed world needs to show leadership in tackling climate change.

The United Kingdom has made up its mind and takes the view that any individuals who disagree with government policy should be ignored. This dogmatic tone is also adopted by the Royal Society, the British equivalent of the US National Academy of Sciences. The Royal Society recently published a pamphlet addressed to the general public with the title "Climate Change Controversies: A Simple Guide." The pamphlet says:

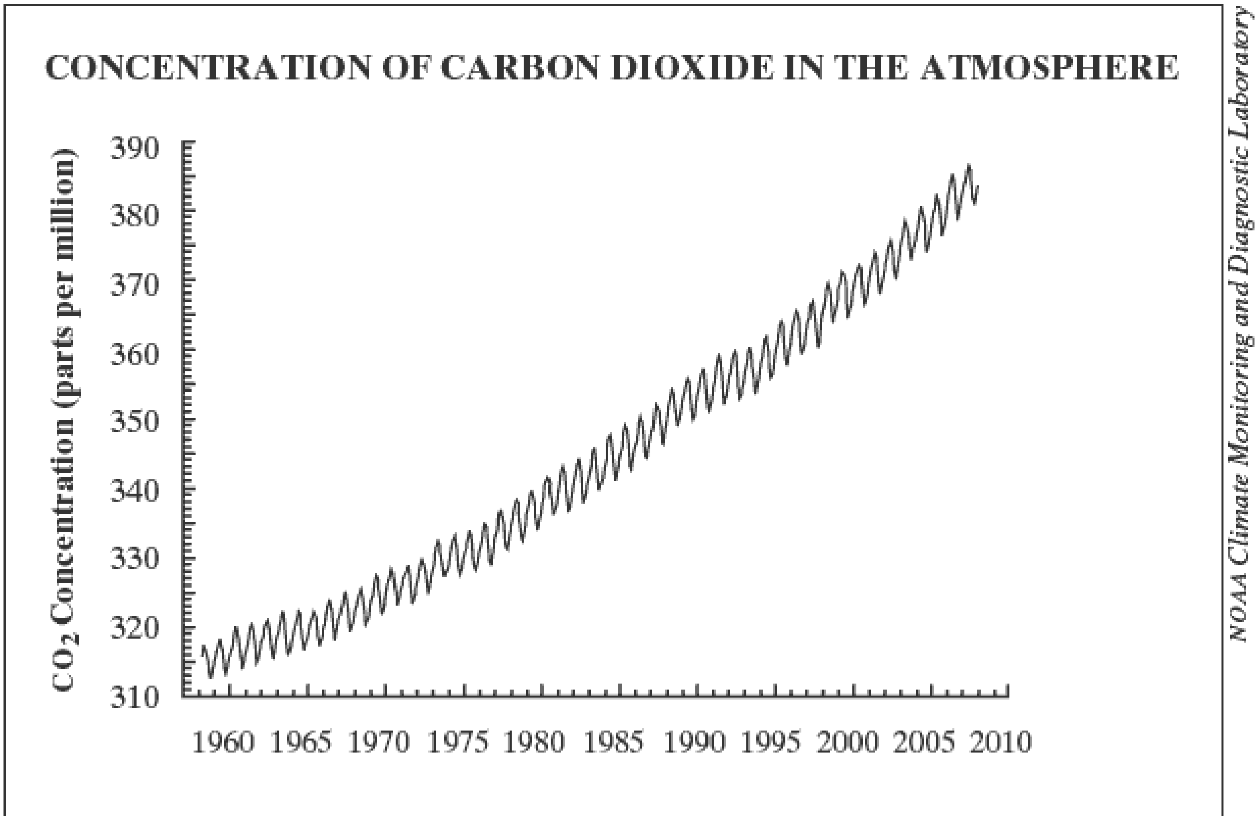
> This is not intended to provide exhaustive answers to every contentious argument that has been put forward by those who seek to distort and undermine the science of climate change and deny the seriousness of the potential consequences of global warming.

In other words, if you disagree with the majority opinion about global warming, you are an enemy of science. The authors of the pamphlet appear to have forgotten the ancient motto of the Royal Society, Nullius in Verba, which means, "Nobody's word is final."

All the books that I have seen about the science and economics of global warming, including the two books under review, miss the main point. The main point is religious rather than scientific. There is a worldwide secular religion which we may call environmentalism, holding that we are stewards of the earth, that despoiling the planet with waste products of our luxurious living is a sin, and that the path of righteousness is to live as frugally as possible. The ethics of environmentalism are being taught to children in kindergartens, schools, and colleges all over the world.

Environmentalism has replaced socialism as the leading secular religion. And the ethics of environmentalism are fundamentally sound. Scientists and economists can agree with Buddhist monks and Christian activists that ruthless destruction of natural habitats is evil and careful preservation of birds and butterflies is good. The worldwide community of environmentalists—most of whom are not scientists—holds the moral high ground, and is guiding human societies toward a hopeful future. Environmentalism, as a religion of hope and respect for nature, is here to stay. This is a religion that we can all share, whether or not we believe that global warming is harmful.

Unfortunately, some members of the environmental movement have also adopted as an article of faith the belief that global warming is the greatest threat to the ecology of our planet. That is one reason why the arguments about global warming have become bitter and passionate. Much of the public has come to believe that anyone who is skeptical about the dangers of global warming is an enemy of the environment. The skeptics now have the difficult task of convincing the public that the opposite is true. Many of the skeptics are passionate environmentalists. They are horrified to see the obsession with global warming distracting public attention from what they see as more serious and more



A graph showing rising concentrations of carbon dioxide in the atmosphere, based on the measurements of the scientist Charles David Keeling at Mauna Loa, Hawaii. As Freeman Dyson explains, the wiggle in the graph gives us 'a direct measurement of the quantity of carbon that is absorbed from the atmosphere each summer north and south by growing vegetation, and returned each winter to the atmosphere by dying and decaying vegetation.' The fact 'that the exchange of carbon between atmosphere and vegetation is rapid is of fundamental importance to the long-range future of global warming.'

immediate dangers to the planet, including problems of nuclear weaponry, environmental degradation, and social injustice. Whether they turn out to be right or wrong, their arguments on these issues deserve to be heard.

Notes

[*] See Nicholas Stern, The Economics of Climate Change: The Stern Review (Cambridge University Press, 2007).