WORLD•WATCH

WORKING FOR A SUSTAINABLE FUTURE

How Economists Have Misjudged Global Warming

by Robert U. Ayres

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Part One of Two

How Economists Have

The Bush administration's rejection of the Kyoto climate treaty is based on a fallacious economic theory. The proof that this theory is wrong lies in the real history of how technological progress drives economic growth.

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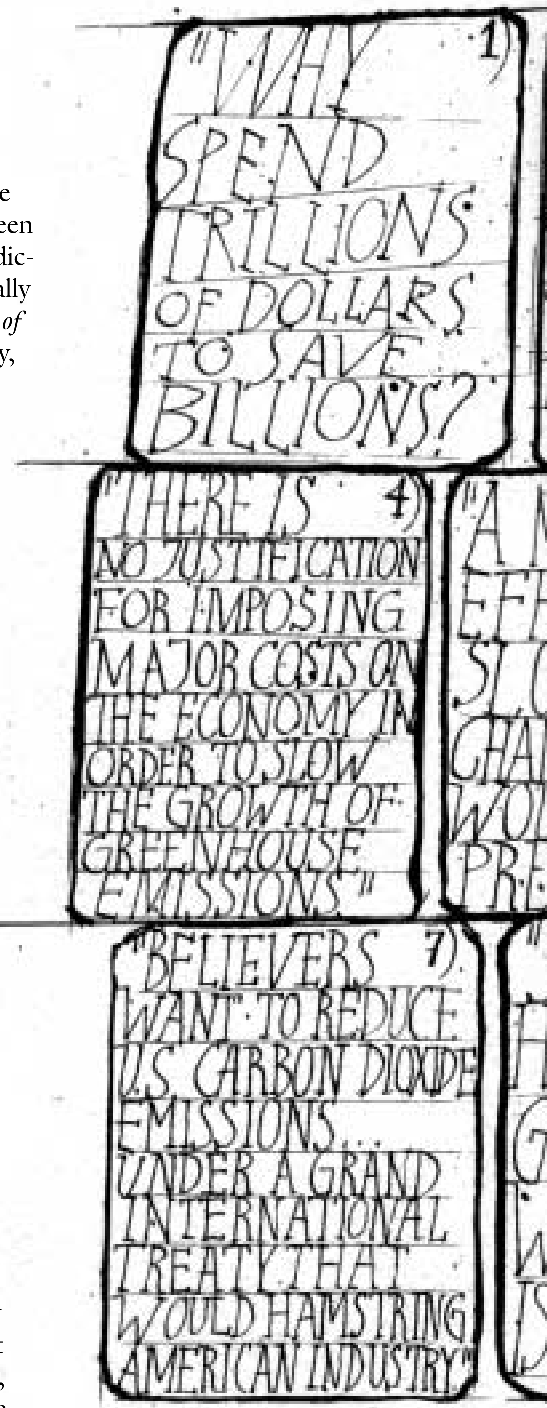


ILLUSTRATION BY ROLF LAUB

A deep chasm has opened between scientists and economists over the issue of global warming. To some degree the chasm has always been there, because economists have never been able to achieve the predictive rigor of the hard sciences. But the rift was increased dramatically by the Bush administration's new energy policy, as presented in its *Report of the National Energy Policy Development Group* authored by Dick Cheney, Colin Powell, Paul O'Neill, Gale Norton, and others in April 2001.

The Cheney report was quickly put together and based on a virtually unquestioned assumption that the only way to keep the U.S. economy healthy is to greatly increase its supply—and consumption—of coal, oil, and natural gas. It simply side-steps the findings of the monumental *Climate Change 2001: Third Assessment Report*, by the Intergovernmental Panel on Climate Change (IPCC), which warns that we may be courting climatic catastrophe unless our burning of fossil fuels—and resulting production of carbon dioxide emissions—is sharply reduced. The IPCC Report is based on five years of intensive investigation by the leading climate scientists of more than a hundred countries. Curiously, the Bush team is on record as unwilling to trust the "uncertain science" of global warming. Yet it unhesitatingly puts its faith in the vastly more uncertain science—if that is the word—of long-term economic forecasting.

When the Bush energy policy was announced, environmentalists—and others who had expressed concerns about whether human industries are on a sustainable course—were deeply distressed. The Bush position seemed so utterly at odds with what the scientists have been saying—and saying with increasing urgency. But even more than distressed, they were perplexed. Why would such a globally resounding voice as that of the IPCC be shrugged off? Some critics averred that it was Bush's and Cheney's oil and coal industry connections, and their need to pay off industry political contributors (who contributed heavily to their election), which accounted for the anti-IPCC stance. Some said it was Bush's fear that voters would be angered by any short-term increases in gasoline prices, as would likely result from any serious cuts in carbon dioxide emissions. And both factors may well have carried some weight.

Recall, however, that the U.S. Senate rejected U.S. participation in anything resembling the Kyoto agreement long before Bush and Cheney came into office. Moreover, the National Energy Policy (NEP) report was never really offered to the public as a rebuttal to the IPCC report, because it never addressed most of the scientists' concerns. Whereas some 1,500 climate scientists had spent millions of research hours (and thou-

Misjudged Global Warming

1) WILLIAM NORDHAUS, YALE; 2) U.S. COUNCIL OF ECONOMIC ADVISORS; 3) JONATHAN ADLER, *NATIONAL REVIEW*; 4) MATTHEW KIERNAN, WALL STREET FINANCIAL ADVISOR; 5) WILLIAM NORDHAUS, YALE; 6) WILLIAM JOHNSTON, CEO, NEW YORK STOCK EXCHANGE; 7) OHIO NEWSPAPER EDITORIAL; 8) *WALL STREET JOURNAL*; 9) GLOBAL CLIMATE COALITION

sands of super-computer hours) tracking the role of industrially produced CO_2 in warming the planet, the NEP report allocated just five paragraphs to the subject, and did not even include the terms "carbon dioxide" or "greenhouse gases" in its glossary. Rather than being a scientific rebuttal, the government report was put forward as an alternative to science.

DISCOUNTING

In practice, the task of quantifying and comparing present costs and future benefits (or the converse) is often virtually impossible to accomplish with any confidence. I am particularly aware of this difficulty because I was a small fly on the wallpaper at the scene of some of the early efforts to apply benefit-cost analysis to real-world issues. In those days (the late 1960s) a few environmental economists were concerned about excessive U.S. government investment in building dams on small rivers.

At that time, the U.S. Army Corps of engineers had become a dam-building agency. The Corps had become heavily involved in this activity during the construction of the giant Tennessee Valley Authority (TVA) and Grand Coulee projects in the 1930s. When those jobs were completed, the Army engineers needed new sources of employment. In their presentations to the U.S. Congress, they justified their proposals for more dams on the basis of optimistic estimates of future recreational and other benefits (i.e. the number of future visitors and how much they would spend) which they discounted at interest rates less than 3 percent, which was the lowest rate paid at the time on extant long-term government bonds issued back in the 1930s. By the same argument the apparent monetary costs of construction (bond interest payments) was understated using the same assumption. Environmental economists at Resources For the Future Inc. (RFF) tried to develop a methodology for yielding more realistic assessments.

One of the rules of thumb that came out of that experience was that, to avoid foolish capital investments, future benefits should be substantially discounted—preferably by at least 8 percent. Now, ironically, it is the high discount rates attached by economists to the future benefits of avoiding greenhouse warming that make those benefits seem hard to justify in benefit-cost terms. In retrospect, what makes this bit of economic history particularly ironic is that in those days, environmental damages—such as the destruction of wetlands or disruption of fish spawning patterns—were not even counted among the costs. The avoidance of those costs, of course, would make the uncounted future benefits even larger.

To be accepted so easily by the entire Republican leadership, and a few Democrats as well, it had to be not just a politically persuasive argument, but a declaration based on a fundamental belief system—an economic ideology founded on certain assumptions not even subject to challenge.

In a recent piece for the *New York Review of Books*, the environmental author Bill McKibben writes that these two documents "offer competing blueprints for the twenty-first century," and that "it would not be hyperbole to say they outline the first great choice of the new millennium, a choice that may well affect the planet throughout the thousand years to come." If that is so, then the arena in which the battle for the planet's future will be played out is not primarily in the evaluation of the IPCC's atmospheric science at all, but in the evaluation of those rarely questioned assumptions on which the conservative economic ideology is founded.

If McKibben is right, environmentalists who continue to argue defensively about the soundness of IPCC climate models, or even about the moral failures of a policy that ignores future generations, are barking up the wrong trees. True, someone who argues on such grounds may eventually be vindicated, if catastrophic damage to the U.S. coasts or crops, or the drowning of a Pacific island nation, proves the Bush-Cheney policies to have been tragically misconceived. But such vindication would come too late to be of much help, less consolation. To change the policy before the damage is done, it is necessary to challenge—and expose for the fallacies they are—the hidden assumptions that lie behind these otherwise incomprehensible positions.

To be more specific, the administration's position on the Kyoto climate treaty, as we have heard from countless government spokespersons and TV talking heads, is that any major government intervention to reduce CO_2 and other greenhouse gas emissions would "harm the U.S. economy." In effect, it is argued that the costs of any government-inspired actions aimed at reducing greenhouse emissions will greatly exceed the discounted present value of the future benefits. The term "discounted present value" is an economist's jargon for the idea that costs are greater if paid now than if paid later (see box at left). That's because if we spend the money now we can't be earning interest on it later; and besides, society will presumably be richer later so it will be easier for our descendants to pay than it is for us. By the same argument, benefits to be received in the distant future are worth less to us now than they will be worth to our (richer) children who get to enjoy them.

The assertion that measures to reduce emissions will be very costly causes many business people to react negatively, in part, because it seems—at first—so obvious. Moreover, this assertion is almost never challenged by anyone with business or academic credentials. It is accepted as revealed truth by the most presumably objective and knowledgeable of the economically savvy news media, such as *The Economist*. One might easily say, *of course* it will be costly. After all, we are implicitly talking about fundamentally restructuring the energy supply and distribution system of the world, not just building more of the same things, as the Bush team wants to do. (But the Bush program of building lots more coal-fired and nuclear power plants would be costly too.)

In reality, however, accessing costs is not that simple. To begin with, costs (think of them as investments) are not very meaningful unless paired with their associated profits or benefits. It cost a lot to launch the auto industry at the end of the 19th century. But that launch also created jobs, generated revenues for all kinds of old and new businesses, brought astronomical profits to (some) investors, and provided new services to consumers—on a scale that the manufacturers of horse-drawn carriages could hardly have imagined. Unfortunately, the "it-will-cost" argument often gets hung up on the highly political question of who will pay and who will enjoy the future benefits—or in this case, the avoided damages. Will the benefits be enjoyed by those who must immediately pay higher taxes or higher fuel prices? In other words, what can we offer in the near term to satisfy skeptical investors who would otherwise prefer to stay with business-as-usual and simply hope that the predictions of future climate disaster are wrong?

Most scientists and engineers will probably agree with most economists that rapid introduction of a new and unproven technology will almost always raise costs in the short run. Why? Because it means skipping stages in the normal evolutionary development process, making decisions before the facts are all in, using off-the-shelf components whether suitable or not, paying premium prices for custom designs, selecting contractors on the basis of existing production capacity rather than long-term potential, and so forth.

True, there are sometimes situations in which a more eco-efficient technology is already available—one that is both cheaper to use and less polluting than what is in general use. This would not happen in a perfect competitive market where all actors had perfect information, of course. But in the real world it does happen sometimes. These opportunities are what the energy researcher Amory Lovins calls "free lunches," and we would be well advised to seek them out and partake of as many as possible. But few who know the subject in depth believe that eating free lunches can avert short-run cost increases to energy consumers altogether. Part of the reason for this is that the only sure way to encourage people to use less energy rather than more is to raise the price. It can make sense to subsidize one form of energy while taxing another. But overall, the price paid by consumers of fossil fuels will have to go up if the output of CO_2 is to go down. In this sense, there is no free lunch.

The real question is not whether the short-run cost increases will result from accelerated introduction of renewables and substitution of capital investment (e.g., in heat pumps, better insulation, and better windows) for energy consumption. They will. The question is whether these short-term increases can be compensated not only by immediate environmental benefits and later cost savings (as scale economies kick in), but also by other long-term benefits. I mean new products, services, jobs, and profits resulting from the introduction of completely new spin-off technologies and new applications of these technologies. That was what happened after Thomas Edison's introduction of his system for electric lighting. It is the sort of thing we must hope for—and actively seek—now.

The issues are rarely presented to senior governmental decision-makers in such terms. More often the cost issue is presented in isolation, and the possible spin-off benefits are ignored precisely because they are hypothetical and hard to quantify.

Well-meaning Attempts at Cost-Benefit Analysis

In the 1980s, NASA scientist James Hansen first asserted to the media that "greenhouse warming" had already begun, due to widespread burning of coal, oil, and natural gas. He was denounced, even by some fellow scientists, as an alarmist. Nonetheless, scientists all over the world began mobilizing to study such indicators as the surface and upper-atmospheric temperatures of the planet, the melting of polar ice, and the carbon dioxide content of glaciers, the oceans, and the atmosphere, and in the 1990s global warming became a volatile political issue. At first, many economists tried to assess this enormous phenomenon the way RFF economists had once tried to evaluate dam-building projects (see sidebar, page 14). But from the outset, the endeavor has proved vexing.

Logically, to assess the economic impacts of all these effects in a cost-benefit framework means examining three broad categories of projections: (1) the future costs of any measures taken to mitigate the warming; (2) the future costs of any damage likely to be done if the warming is not mitigated; and (3) the future spinoff benefits of undertaking such mitigation. To make useful projections, though, it is first necessary to make some assumption about the extent of the damage the warming will bring—and therein lies a major difficulty.

To begin with the evaluation of potential dam-

In the late 18th century, a shortage of charcoal (needed for heating, smelting iron, etc.) posed a new threat to the British Empire, the world's dominant economy at that time. There were two options: Do whatever necessary to expand charcoal production. . . or invest in developing a substitute and overcoming problems of getting the new technology up to speed.

If the first option—to stick with charcoal—had prevailed, the result would likely have been a denuded landscape and a stagnated economy. Instead, the development of coal opened the way to a vast proliferation of economic growth that the original investors could never have imagined.

Today, we are faced with a similar challenge: rising

Shortage of CHARCOAL in the 18th Century

(Largely due to deforestation for building the ships of the British navy)

Reactionary Option:

Go farther afield for wood to make **more charcoal**

Further deforestation and scarcity

Rising price of charcoal

Cutbacks in energy use

Stalled development of new technologies requiring more than animal energy

Economic stagnation

Progressive Option:

Develop **coal as a substitute**

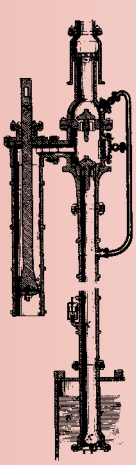
Problem: long trial-and-error needed to replace charcoal in iron smelting

led to eventual success

Begin mining coal

Problem: mine shafts go below water table, so water must be pumped out by horse-driven treadmill

Solved by invention of **steam-driven pump**



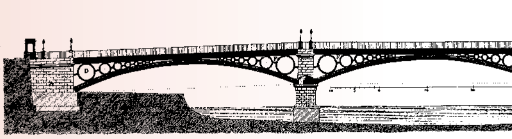
which lowered price of coal

and provided feedback loop to new applications for **steam engines**

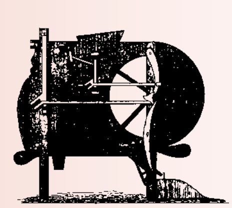
such as **boring machines** for making cannon barrels. . . and cylinders for more powerful steam engines

leading to still more applications, including **ocean-going ships** and **locomotives**

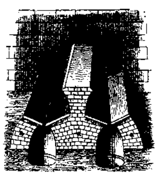
which increased demand for infrastructure, including **tunnels** and **bridges**



and which led to new applications of coal, including **coal gas for lighting**



and to mechanization of **agriculture** with inventions like the winnowing machine global demand for energy, in the face of rising pollution and global warming. Again, there are two options: Do whatever necessary to expand fossil fuel production . . . or invest in developing full substitutes for coal and oil.

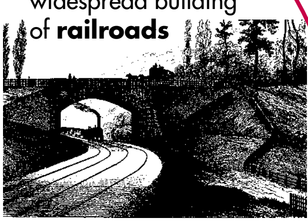


accumulating abundant by-product, **oven coke gas**

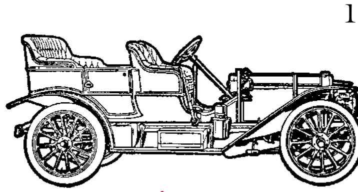
lowering cost of **cast iron**, then **wrought iron**, and later Bessemer **steel**

which provided the idea for an **internal combustion engine for factory operations**

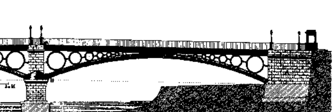
leading to new applications of steel, including widespread building of **railroads**



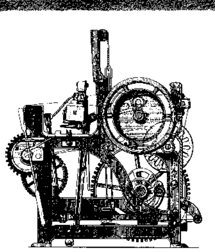
which, combined with new invention of carburetor, led to a new application: making **cars**



providing feedback loop further increasing value and demand for **steam locomotives**



which led to the development of highway **construction, bridges and tunnels, traffic lights, gasoline, lubricants, batteries, filling stations, repair shops, parts retailers, motorized off-road equipment, motels,** and hundreds of other businesses.



and leading to mechanization of the **textile** industry with machines like the **power loom**

ages, public perceptions of what warming could mean have varied wildly. People living in cold climates, including many Russians and Scandinavians, were initially inclined to see warming as being quite beneficial, insofar as it might bring longer growing seasons and balmier weather. Vineyards might grow in Scotland, and beach resorts might boom in the Baltic. Those living in South Asia, on the other hand, worried about droughts, floods, changes in the monsoon pattern, pests, outbreaks of new diseases, and resurgence of old ones like malaria. Warming on the global level has hundreds of different kinds of potential local impacts. Trying to attach reliable monetary costs or benefits to each of them proves to be a greater challenge than that of the legendary blind men trying to describe an elephant.

To illustrate just one problem, consider the future impact of warming on the Mississippi River Delta. It will likely be hit, sooner or later, by massive flooding, whether from the north or from the encroaching Gulf of Mexico. This isn't like trying to assess the impact of a dam, where the altered level of the river water is known precisely. For the world at large, the IPCC's *Third Assessment Report* forecasts a significant future increase in sea level due to ice-melt and thermal expansion. But the extent of the sea level rise (and therefore of the Gulf of Mexico's rise) will depend on the amount of warming, for which the IPCC's projected range is disconcertingly wide—from a moderate 2.7 degrees F. to a calamitous 11 degrees F. over the next century. Moreover, that range has changed since the Second Assessment in 1995, and could change again.

Then there are the uncertainties about how much a given level of atmospheric warming contributes to increased storm severity (such as the strength of a hurricane blowing in from the Caribbean), or how much sea-level rise contributes to the severity of storm surges (such as the likely height and reach of a wave rolling in from the Gulf). But even if that can be agreed on, there's the question of assessing what New Orleans is worth as a city. When houses or streets are destroyed, or livestock drown, or cotton fields disappear into the mud, it's not so difficult to assess the loss. Insurance companies do it all the time. If we know what it costs to rebuild them, we know what it's worth to save them. But how do we assess the worth of a human life lost or saved? Beyond that, how do we assess the worth of a community or culture?

Considering just the value of an individual life is hard enough. Remember, it's not quite the same question as asking how much life insurance a person has been willing to buy. If the value is set by society as a whole, do we value everyone the same? Do we value young children as much as economically productive adults? Is the value of the life of an employer of thou-

What History Tells Us – CASE 2

Constraints on Fossil Fuels today

(Global warming, health impacts of pollutants, dependence on foreign oil)

Reactionary Option:

Go farther afield for coal and oil (drill in wildlife refuges, under lakes, and off coasts; lop off mountain tops; strip mine)

Leading to increasing conflicts—over environmental impacts and over control of oil supply

Leading to rising constraints on energy use

Leading to environmental degradation and economic stagnation

Progressive Option:

Invest in higher short-term costs of development, to bring wind, solar photovoltaic, and fuel cell resources more rapidly up to scale as full substitutes for fossil fuels, especially when combined with more efficient energy use

Launching a new generation of technology-driven economic development—many elements of which can only be sketched

- Hydrogen-powered cars, mass transit, trains, and boats
- Hydrogen fuel infrastructure and retailing
- Architectural retrofitting (for heat and power)
- Ocean currents energy extraction
- Ocean tides energy extraction
- Photovoltaic building materials (roofing, walls) manufacture
- Energy-efficient building materials manufacture
- Energy-efficient appliances manufacture

Driving new economic growth, less dependent on materials consumption

sands of workers the same as the value of the life of an unemployed (or unemployable) person? Is the value of a criminal the same as that of a philanthropist or scientist or artist? And there are some other questions of this ilk that I won't raise now because they would likely enrage you, but that would have to be asked—and answered—in order to assess the value of a life saved. Thinking about this issue has long been giving economists headaches. Most will now concede privately, if not publicly, that it's virtually impossible to quantify the benefits of avoiding really major catastrophes, such as those brought on by climate change. The famous precautionary principle is, as much as anything, an admission that it's better to be safe than sorry when we can't really know the magnitude of the risks.

Calculating the direct *costs of avoiding* climate change isn't much easier. One common simplification is to focus on what it would cost to substantially reduce carbon dioxide emissions, based on the argument that carbon dioxide accounts for at least half of the problem. This suggests that abatement policy should be focused on burning less coal and oil. That could be achieved, at least to some degree, by conservation and substitution of other energy sources for coal-burning electric power plants. Reviving the largely moribund nuclear power industry has been proposed as an option by some (and by the Bush NEP report), but strongly opposed by much of the public, including me. In any case, allowing for safety and disposal costs, nuclear power today is more costly than today's coal-burning power plants. Moreover, to plan, design, and build a nuclear plant from scratch takes ten years, on average. The suggestion that new nuclear plants could relieve California's "energy shortage" any time soon is either dishonest or naïve.

Other alternative power sources such as solar photovoltaic and wind, less well-developed than nuclear power, would cost even more to introduce on a large scale in a very short time. To put "large scale" in its proper context, bear in mind that the present contribution by alternative energy sources, while growing fast, is still only a very tiny fraction of total demand. Costs should decline as the scale of output rises, but nobody can say with confidence how much. It is difficult to describe a package of technologically proven and economically viable alternatives to fossil fuels for which accurate future cost calculations are feasible.

And, while world leaders have battled to a deadlock over a Kyoto treaty that would reduce CO_2 emissions by a mere 5 percent, remember that the scientists of the IPCC agree that CO_2 would have to be reduced by *60 to 80* percent to stabilize climate—so the assessment of costs would have to focus on that much larger shift in the technological mix. In short, there are so many "ifs" in the assessment of what it will cost to phase out the bulk of our fossil-fuel dependence that here, too, economists have been at a loss.

A Too-Clever Simplification

It is at times of great frustration that attractive simplifications tend to pop up. Demagogues depend on them. Simplification removes the burden of thinking too hard, and replaces the discomfort of facing ethical ambiguities with the security of faith. In effect, that is what has happened in the arena of climate change economics.

The Yale University economist William Nordhaus is not a demagogue, by any means. Back in the 1980s, he made a serious effort to add up the potential costs of climate warming, on a sector-by-sector basis. In this effort he focused entirely on losses of output that could be directly attributed to warming, with no attention to indirect (and incalculable) consequences such as disease, migration away from coastal or estuarine areas prone to flooding (from storms and sea level rise), the impact of landless refugees on social order and social services in other areas, and so on. Naturally, disagreements arose. Other economists made slightly different estimates based on different assumptions. But all of the studies assumed that the costs of climate warming could be measured in terms of decreased economic output.

And what of the costs of amelioration? This is where Nordhaus came up with a theory that—as it has been subsequently seized upon by others, including the authors of the Bush Energy Policy Report—sweeps aside all the vexations of trying to do a detailed cost-benefit analysis of global warming. His theory has two parts. First, he assumes (with the vast majority of his fellow economists) that past rates of economic growth were the result of "optimal" choices, on the grounds that firms with perfect information acting rationally in a free competitive market would tend to make optimal choices. Next, he extrapolates these optimal past growth rates far into the future. He doesn't actually say so, but one can safely infer that such a long-range projection is reasonable if, and only if, economic growth would continue automatically, indefinitely, and independent of governmental intervention. This sounds like a theory written in an ivory tower, far from everyday experience. But since most economists go along with it, let's take it seriously and see where it takes us.

This hypothetical future growth trajectory is regarded as a "baseline." But of course, assuming we humans have free will, the future can presumably be altered by policy changes taken now. Nordhaus now says (in effect) that the only possible impact of government interventions to reduce greenhouse gas (GHG) emissions will necessarily be to reduce economic growth from the optimum trajectory. Why? Because the government interventions must reduce the "option space" (the range of possible choices) available to entrepreneurs. For instance, they might be prevented by regulations from burning the cheapest fuels.

Nordhaus thus assumes that, in the event of any new regulation to reduce GHG emissions, the set of all possible choices open to each firm in the economy will be smaller in the future than it is now. If one accepts that assumption—as many economists do—then it follows logically that the tighter the regulatory constraints become, the slower the rate of economic growth will be. The cost of GHG reduction can then be equated to the cumulative difference in future GDP under unconstrained (high growth) and constrained (lower growth) cases.

To convert this clever theory into a numerical estimate, a quantitative relationship between GHG reduction and abatement costs must also be assumed. This is another area where real-world complications intrude. But here Nordhaus once again manages a nimble side-step. In a nutshell, he argues that, even if the reduction from the assumed "optimal" growth rate caused by government intervention is very small, over a period of decades it would amount to a very large sum. If it were a reduction of merely 0.1 percent per year, for example, the cost over the next century could come to several trillions of dollars. Comparing those "trillions" to the mere "billions" that purportedly would be the total benefit gained by sharply reducing CO_2 emissions, constitutes the essence of the argument against U.S. ratification of the Kyoto agreement.

As it happens, William Nordhaus provided the principal economic input to the U.S. negotiations in Kyoto—and to the country's eventual refusal to cooperate with the Kyoto process altogether.

Where Scientists Don't Buy It

So, it is this highly simplified theory of entrepreneurial option constrained, that explains the "economic damage" refrain we have heard so often since environmentalists —backed by the IPCC scientists — first began warning of the need to reduce greenhouse gas emissions. But it is also here that economists and non-economists tend to part company. Most neoclassical economists accept Nordhaus's main theoretical assumptions, and (therefore) his generic conclusions.

However many other people, including environmentalists, many engineers and most "hard" scientists—those who study the real economy as it is embodied in the real physical world—tend to disagree. Although I have worked in both worlds, I count myself among those who disagree, and I think I can pinpoint why. There are three basic problems with the Nordhaus model:

➤ **The Myth of Optimal Growth:** The assumption that past growth has been optimal ("because rational profit-seeking firms with perfect information operating in a perfectly competitive economy would tend to make optimal choices") is dubious. Indeed many would say that it is patently absurd. The economy of the past has never been a "free market" that is unconstrained by government regulation. While firms certainly seek to maximize profits, they do not enjoy anything even close to perfect information. If perfect information were freely available, there would be no demand for consulting firms, financial advisors, economists, or any of a host of professions that thrive by selling information, or access to it. Markets are not perfectly competitive, either; barriers to entry can be very high. The most common strategy for a large, established firm is to create barriers for its competitors—as have such companies as Microsoft. Moreover, if business managers' choices were always optimal, there would be no market "bubbles" and no market "crashes." And finally, there is abundant evidence that government interventions don't always reduce economic growth—and that in some cases they are needed to kick-start it.

➤ **Taking Technical Progress For Granted:** Nordhaus assumes that technological progress, and therefore economic growth, will occur smoothly and steadily, automatically and independent of economic conditions (absent government intervention of any kind). Technological progress is thus "exogenous" to the economy. Yet, if you study the history of technology, you will find abundant evidence that economic and/or other crises are often critical to innovation. Major innovations have been triggered by wars or threats of war.[1] Others have been triggered by scarcity or prospect of scarcity.[2] Still others have been responses to powerful new "needs" that were created by previous innovations.[3] A few have been stimulated by the sudden availability (or discovery) of a new resource.[4] In fact, it is more difficult to think of modern innovations that were prompted merely by accident or curiosity.[5]

In short, there is no *a priori* reason, based on history, to expect that a government intervention to restrict the use of carbon-based fuels or to encourage the use of non-carbon based fuels would inevitably inhibit economic growth. Many important technologies have actually been kicked off by the government, via the military. Some have later flourished in the civilian world. Electronic computers, radar, jet engines and nuclear power are just a few. The Internet began as ARPAnet, a military-sponsored project to provide rapid data links between a number of universities. In France, the highly successful Airbus Consortium (which is apparently poised to end Boeing's dominance of the passenger air transport business) and the highly successful TGV high-speed railway system (the world's best) are both results of direct government intervention. Based on the real history of industrial development, there is at least as much

1 Examples include machining technology (for gun manufacturing), submarines, nitrogen fixation (to make explosives), jet engines, RADAR, SONAR, and nuclear power. Computers can probably be added to this list.

2 Examples include use of coal in iron smelting (to replace charcoal), illuminating oil from petroleum (to replace whale oil), food preservation by canning (to feed soldiers on the move), synthetic ammonia (to replace Chilean nitrates), synthetic rubber (to replace natural rubber from plantations then in Japanese hands), and so on. Many important inventions can be traced to the scarcity of human and animal labor on farms and in kitchens, especially in the 19th century United States. Examples include harvesters and combines, tractors, sewing machines, washing machines, dishwashers and others. In modern times, the transistor and semiconductor technology in general arose from a recognition by scientists at Bell Telephone Labs that communications needs would soon overwhelm the electrical power generating capacity of the United States unless more efficient (less power-consuming) devices were developed. This was a clear case of response to an anticipated shortage (of electrical generating capacity). Many modern telecommunications innovations—notably optical fiber technology—arise from similar concerns about the availability of channel capacity.

3 Examples include sewing machines, telegraphs (needed to operate railways), telephones (to meet a newly perceived communications need that telegraphs could not meet), electric light (to meet a demand for better and cheaper light for which candles and gaslight were inadequate), railway signalling systems, night landing and navigational systems for aircraft, etc.

reason to suppose that innovation and growth will be stimulated as inhibited by government.

➤ **The Fallacy of a Static Model:** Now I come to the third flaw in the Nordhaus model. I have left it for last because, from a theoretical perspective, this one is fatal. Let's revisit, for a moment, that standard neoclassical notion that entrepreneurs have perfect information, or at least all the information needed to make optimal choices. In that ideal economy, unlike the real world, all firms competing in the market know all the possibilities for technological choice at all times. They choose the best among a fixed range of possible choices, based on their own mix of capital assets and skills. It seems to follow that if the range of choices is constrained by government action, some of the best choices will be excluded and, *ipso facto*, growth will suffer.

The flaw in this reasoning is its failure to recognize that in the real world, the range of technological possibilities is *not fixed*. There are new technological possibilities being introduced constantly, but by no means randomly. In principle, the choice of R&D projects should be optimal too—meaning that R&D money should flow preferentially to the projects showing the best return on R&D money spent in the past. In reality, though, R&D choices made by government are largely political. Money flows preferentially to the sectors with the biggest firms and the noisiest lobbies. In the United States, it is nuclear power that has received (and is still receiving) the most government R&D money, followed by fossil fuel technologies such as "clean coal." And it's in those industries that the Bush administration plans to put most of its research dollars. Yet if those dollars were really spent on the projects that have provided the greatest performance gains per dollar spent, they'd be spent on conservation technologies, wind turbines, and photovoltaic power.

If the choices available to entrepreneurs are not fixed once and for all, then there is no way they could possibly make optimal choices for the indefinite future, since they do not know now (or ever) what possibilities will be generated by scientific progress in the future. It follows that the entire Nordhaus theory of decreased option space has no basis. The Emperor has no clothes. In short, the intellectual argument underlying the Bush Administration's opposition to the Kyoto Protocol is completely fallacious.

How Could They Have Been So Wrong?

The senior economists who advise governments and teach the next generation of economists are all professors at major universities such as Harvard, MIT, Yale, Chicago, Stanford, and Princeton. How, you might ask, could a group of such obviously intelligent and educated people come to embrace an economic model with such counter-factual assumptions and counter-intuitive implications? The answer, I suspect, has to do with the way in which neoclassical theorists are trained to think about economic systems. Neoclassic economics is the creed now taught in most universities and textbooks. (Nordhaus is now the co-author, with Paul Samuelson, of the most widely read economics textbook of the past half century.) Its students are taught, from their first days as students in "economics 101," to think in terms of abstract entities—"firms"—exchanging abstract goods and services in a perfectly competitive marketplace.

These abstract entities buy capital services and labor (from abstract capitalists and workers), and the goods and services they produce are essentially immaterial. I use that word literally. The producer firms purchase "raw materials" (also immaterial), and there are no troublesome physical wastes or pollutants. In short, real materials and energy are not involved in the neoclassical economic paradigm. The neoclassical system is a kind of perpetual motion machine. It produces and consumes—and grows—

4 Examples of "new" resources that stimulated invention and innovation include coal tar (from coke ovens), which became a source of aniline dyes and many other chemicals; gasoline (and heavy fractions) from petroleum refineries, which led to the development of practical internal combustion engines in sizes small enough for vehicles; and natural gas associated with petroleum drilling. Much of the petrochemical industry now depends largely on products derived from natural gas. It could be argued that electricity on an industrial scale was a new resource. The invention of the electric furnace in the late 19th century created a number of "new" materials for industry, from silicon carbide (carborundum) to superalloys, without which jet engines could not be built. Chlorine became available on an industrial scale only after the electrolytic reduction of salt to obtain caustic soda became widespread in the late 19th century. Similarly, aluminum became available on an industrial scale only after the Hall-Heroult electrolytic process was invented in the 1890s.

5 Examples of inventions for which there was no significant prior need or demand include photography, bicycles, automobiles, aircraft, and rockets. In all these cases the demand was latent and the first users were largely recreational. Broadcast radio and TV can also probably be put into this category. Military uses accounted for much of the early development in the case of aircraft and rockets, as well as advanced telecommunications. The laser is a modern example of an invention that was a complete surprise at the time of its invention and for which major uses did not develop for more than 20 years.

without constraints or limits, except insofar as consumer preferences (for present vs. future satisfaction, for example) enter the picture.

Why so many unrealistic simplifications? The reason is that the real world is far too complex for us to model with any confidence, and economic theorists—like physicists—are searching for general laws that can be applied to a wide range of situations. Starting from the very simple assumptions mentioned above, it is possible to create models that are mathematically tractable (though hardly trivial) and about which theorems can be proved. Then, hopefully, the results can be generalized step by step to more and more realistic cases. It is not a foolish program of research, if the starting assumptions are reasonable, or at least not unreasonable.

The "business as usual" trajectory (allowing for marginal improvements but continuing to depend on fossil fuels) is really a dead end because it excludes any truly potent new technological directions.

For many traditional kinds of economic analysis the neoclassical assumptions are not unreasonable. But for purposes of discussing and assessing policies for long-term environmental sustainability, they are not reasonable. The standard assumption that firms are abstract entities producing immaterial goods and services is an acceptable simplification for many purposes. But it is not appropriate for analyzing a problem arising directly and essentially from the material nature of the goods and services. Greenhouse gases are physical and material in nature. They are also pollutants, and pollutants—by definition—arise from so-called market failures, which means that the standard neoclassical assumption of perfect markets and perfect competition has no place for them. Perhaps that helps to explain why the Bush administration acts—despite its recent lip service to climate change—as though those gases don't really exist.

Furthermore, the assumption that the economy is a kind of perpetual motion machine capable of growth-in-equilibrium forever cannot be accepted for purposes of assessing climate change policies. There are two reasons. The first is that economic growth comes from technological innovation, as the histories of the industrial and communications revolutions amply demonstrate. It involves "creative destruction" through which new materials, new machines, new doctrines and new techniques displace old ones. This is not an equilibrium phenomenon. The second reason is that new technologies do not appear out of the blue—like "manna from heaven"—for no reason. They are almost always developed by deliberate activity to create and disseminate knowledge. And more often than not, this creative activity is prompted by some sort of disequilibrium or scarcity.

With that in mind, let's return to the starting point for this discussion, about calculating the "cost" of intervening to avoid climate warming. Recall that the conventional approach to making this calculation is to assume some business-as-usual growth trajectory, based on extrapolations from recent productivity growth rates, and then to assume slightly lower growth rates corresponding to the case where regulations have been introduced. The cost of regulation is taken to be the difference (or a function of the difference) between the two growth rates.

But, can it be so easy to calculate the future growth of an economic system many decades into the future? Doesn't it depend on rates of population growth, female participation in the labor force, urbanization, education, lifetime working hours, environmental constraints, capital investment, scientific discoveries...and so on and on? Surely, no-one would pretend that these factors have not changed significantly in the past century and are not changing still—some of them quite rapidly. Then how can it be reasonable to extrapolate past growth rates into the future? Or is it that this approach—the Nordhaus notion of an economy that continues automatically, indefinitely, and independent of government action—is essentially unreasonable?

The Mystique of Technical Progress

It is helpful, here, to review a little history of economic thought. In the 18th century when the study of economics began to distinguish itself from "natural philosophy," there were two competing theories. The French physiocrats, as they were called, attributed wealth to agricultural surplus (a gift of nature) and thence to land. The English theorists, as exemplified by John Locke, attributed wealth by contrast to the result of human labor on the land. Adam Smith—and Karl Marx after him—emphasized the role of labor as the primary creator of wealth. Marx distinguished between current labor inputs and "capital" created by past labor. By the end of the 19th century, economists had pretty much settled on capital and labor as the two "factors of production" that should account for economic output.

By the mid 20th century, it was possible to reconstruct historical time series for GNP, labor, and capital investment as far back as the 1870s. Using straightforward statistical methods, it was possible to ascertain how much of GNP growth since the Civil War could be explained by increasing labor supply and how much could be attributed to increasing capital stock. The answer was a great surprise. It turned out that labor and capital together could only account for a small fraction of the growth that had actually occurred. The unexplained residual was named "technical progress." Technical progress, so called, seems to add 1.5 percent or so to the U.S. GNP year in, year out, like clockwork.

Most economists are still using versions of a theory of growth developed nearly half a century ago by Robert Solow, who was awarded a Nobel Prize for his accomplishment. The Solow model, in its simple form, depends only on three variables. The first two are total labor inputs and total capital stocks. (Capital services are assumed to be proportional to the stock). The third variable is the above-mentioned technical progress, which Solow introduces as an exogenous multiplier of a "production function" that depends on the other two variables. The multiplier is usually expressed as an exponential function of time which increases at a constant rate based on past history.

The first economist to focus on technological progress as an economic phenomenon was an Austrian, Arnold Schumpeter, who moved to the United States and taught at Harvard. It was Schumpeter who pointed out (in his PhD thesis in 1911 or so) that innovation is the driver of growth, and that innovators have economic incentives to achieve temporary monopolies that allow "supernormal" profits. This is still the incentive for Intel and Microsoft. It is what drives drug companies to develop new drugs, and McDonald's to develop new hamburger combinations. It was Schumpeter, by the way, who coined the phrase "creative destruction" I used a few paragraphs back. Unfortunately, there has never been any real quantitative theory to explain Schumpeterian technical progress, although some economists made careers trying to explain it in terms of other variables. This activity was called "growth accounting." So, perhaps it is with some justice that technical progress has been called "manna from heaven." In practice, most economic growth theorists since Solow have ignored the problem, like the mad aunt in the attic that no one mentions, and simply assumed that such progress will continue into the future as before.

The Solow growth model is not intellectually satisfying, of course. And the standard model has other drawbacks, as well. For instance, it holds that the role of capital investment as a driver of growth necessarily declines over time. This is because the capital stock eventually becomes so large that annual investments are needed simply to compensate for annual depreciation. When this point of saturation is reached, further growth per capita can only result from technical progress. This feature of the model also implies that countries with a small capital stock will grow faster than countries with a large capital stock. Thus, the model predicts gradual convergence between poor and rich countries.

Growth data has been accumulated by the World Bank and other agencies for many decades. However neither the expected saturation nor the convergence phenomena are clearly indicated by the data. So far, there is no convincing evidence of capital saturation at all. There are examples of convergence, but there appear to be more examples of divergence. Nor is there any explanation of why technical progress is faster in some countries than in others. In short, the standard economic model is—and has been for some time—in urgent need of repair, if not major revision.

Growth as a Positive Feedback Process

One other feature of the standard Solow model is very troublesome in the long run context. Quite simply, the model treats natural resource consumption in general, and energy consumption in particular, only as a consequence of economic activity (as the American economy grows, we'll "consume" more energy), not as a causal factor. Yet the causal relationship surely runs both ways. The engine of economic growth is a positive feedback cycle, in which declining costs of producing goods and services stimulate increased demand for those goods and services. They also stimulate the creation of newer goods and services. (Increased demand for cars stimulated demand for paving machines, traffic lights, and personal-injury lawyers—and eventually for Gulf War weapons, traffic reporters, drive-in fast-food restaurants, and advertising copywriters.) Increased demand for the expanding array of products and services triggers increased investment and increased scale of production. Investment may be strictly in bricks and mortar or it may also include research and development (R&D). Economies of scale, along with process improvements resulting from R&D together with "learning by doing," then yield further cost savings—which lead to further price reductions, and so on around the loop.

This feedback cycle works for all kinds of goods and services, of course, but it is particularly powerful in the domain of energy conversion and mechanical power. The Industrial Revolution began with a shortage of charcoal due to deforestation (much of it for timber to build navy ships) in the 16th and 17th centuries. Coal was discovered, and mining began. But soon the mine shafts went below the water table. It was necessary to pump the water out of flooded mine shafts. Horses on a treadmill were the usual source of pumping power until Thomas Newcomen built a steam engine (based on some borrowed ideas) and commercialized it for application in the mines. Coal-fired steam engines, even very crude ones, could pump water more cheaply than horses on a treadmill. The price of coal dropped, demand rose, and in the late 18th and early 19th centuries new applications of coal—such as gas for lighting in cities—rapidly emerged. At the same time, growing demand for steam engines increased and triggered important design innovations (especially James Watt's improvements) that sharply increased their efficiency and reduced their cost. Steam engines powered boring machines (to make cannons but also to drill out the cylinders of more powerful steam engines!), drove river boats upstream, carried coal cars from mines to ports, drove mechanical looms and eventually drove railways and ocean-going ships.

After a long trial-and-error learning process, coal (and later, coke) also replaced charcoal in iron-smelting and brought about the widespread availability of cast iron, then wrought iron, and finally Bessemer steel. The major market for cheap steel was to build the railway network and its associated infrastructure, such as bridges. Then came ships and high-rise buildings. The first industrial revolution was certainly powered by coal and steam, and the fingerprints of feedback are pervasively visible.

Greenhouse gases are pollutants, and pollutants–by definition–arise from so-called market failures, which means that the standard neoclassical assumption of perfect markets and perfect competition has no place for them. Perhaps that helps to explain why the Bush administration acts–despite its recent lip service to climate change–as though those gases don't really exist.

The energy-power feedback cycle did not stop in the mid 19th century. But technical progress opened up new avenues for further industrial development—and for still more feedback loops. The rapid growth of the steel industry after 1870 required vast quantities of coke. Coke is made from coal, but the pyrolysis process yields a gaseous waste known as coke oven gas. At first this material was just flared off. But its abundant availability led inventive minds to wonder whether such gas might somehow be used as a fuel. Soon, a new kind of engine was invented, which could burn fuel inside the cylinders and harness the hot expanding combustion products to drive the pistons. This "internal combustion" engine had several fathers, but it was fully commercialized (in 1876) by Klaus Otto in Cologne, Germany, near where the coking industry was centered.

Otto's compact engines were designed to be stationary, for use in small factories and shops. However one of his engineers, Gottlieb Daimler, took the idea further. With Wilhelm Maybach, he designed a miniature version of Otto's engine, with two cylinders. Thanks to Maybach's invention, the carburetor, it was capable of burning a liquid fuel. Daimler partnered with Karl Benz, a carriage manufacturer, to produce horseless carriages. Their first model was named for Benz's daughter, Mercedes. The rest is well-known history.

Whence came the liquid fuel burned by Daimler-Maybach's engines? It, too, was a virtually costless waste product of the distilleries that made "illuminating oil" (kerosene) from "rock oil" (crude petroleum) to replace whale oil in household lamps. Whale oil had been getting scarce for several decades, as demand outstripped the supply of sperm whales. Rockefeller's Standard Oil monopoly was based on "illuminating oil"—a big business in the late 19th century. Gasoline, a light fraction too volatile for household use, was either discarded or used wastefully for dry-cleaning or other minor applications. But in 1890 or so, Daimler-Benz (and hundreds of competitors that soon appeared) put this refinery waste product to work in their new horseless carriages. Twenty years or so later, it was gasoline that was the primary product of petroleum refineries, and soon after that it was necessary to find ways of "cracking" heavier fractions and recombining lighter fractions to increase the gasoline supply. Again, the fingerprints of feedback are everywhere to be seen.

Another major innovation of the late 19th century was the use of steam engines, especially the new steam turbines, to generate electric power. Like petroleum, this technology was first used for lighting. The demand for brighter and cheaper light provided an enormous impetus to the nascent electrical industry. But no sooner did technical progress in electrical engineering (largely thanks to Thomas Edison) make it possible to generate electric power cheaply on a large scale, than a host of completely new applications emerged. These included electric motors (soon applied to streetcars, elevators, washing machines, refrigerators and all sorts of factory machines), and electric furnaces capable of reaching extraordinarily high temperatures and making totally new materials such as silicon carbide (carborundum) for cutting tools, calcium carbide to make acetylene gas for lighting and for welding, tungsten filaments for incandescent lights, and stainless steel.

Today, electric power is rapidly replacing all other sources of mechanical power other than for transportation and off-road machines. It is electric power that makes possible the systematic use of the electromagnetic spectrum for communications (telegraph, telephone, radio, radar), entertainment (TV), and electronic data processing. It is the merger of electronic data processing with telecommunications that may provide the motive force for the next burst of economic growth. Nevertheless, most of the electric power in the world is still produced by steam turbines powered by burning coal or other fossil fuels. This is the dependency that must be broken—and broken soon—if the climate warming process is not to get out of control.

Breaking the Cycle

To summarize, there is every reason to conclude that technical progress up to now has been largely driven by the energy-power feedback cycle. The advent of microelectronics-based information technology in recent decades has introduced another significant—but not yet independent—driver of technical progress. Biotechnology is likely to be increasingly potent in the coming decades. But declining energy prices, and increasing demand for fuel and power, continue to play an important role in the economic growth machine.

In the context of long-term economic forecasting, this is a vital point. It means that future economic growth along the present trajectory must mean large increases in energy and natural resources consumption. The ratio of GNP to energy may now be declining slowly (for the most industrialized countries), but the consumption of energy and materials per capita is still increasing. To those who are trying to envision a sustainable economy, "dematerialization" is a compelling notion. But it is not yet a reality. Economic growth and materials/energy consumption are still very tightly linked. If "dematerialization" were really enforced, today or tomorrow, economic growth would instantly stop and go into reverse. In that respect—in the short run—the intuitions of the Kyoto skeptics are correct. Economic growth over the next few years is still very much dependent on continued increases in energy consumption accompanied by declining prices.

In the long term, however, the skeptics are probably quite wrong. One reason is that the existing energy-power feedback system is itself running out of steam—so to speak. There are not many possibilities for increasing fossil energy conversion efficiency, or developing marvelous new materials from petrochemicals, or exploiting further economies of scale. On the contrary, oil will have to be drilled deeper, further and further offshore, or in the arctic, or recovered from shale, all of which will increase costs. Carbon dioxide from electric power plants will have to be captured and sequestered underground or deep in the ocean. Again, costs will increase.

The "business as usual" trajectory (allowing for marginal improvements but continuing to depend on fossil fuels) is really a dead end because it excludes any truly potent new technological directions. By "potent," I mean technologies with applications beyond their original narrow application—as the technology for creating electric light made possible so many other new and previously unimaginable products and services, for example. In fact, the longer the existing system is functioning and keeping costs and prices low, the harder it is for radical new approaches to break into the charmed circle.

It is no accident that major breakthroughs in the past have often followed a crisis of some sort. People started to dig coal when charcoal became too costly. People started searching for "rock oil" and learning how to drill for it and refine it because the sperm whales were becoming scarce. The Germans developed synthetic ammonia technology to free themselves from dependence on British-controlled Chilean nitrates. In the second war, they developed coal gasification and liquefaction technologies to replace petroleum supplies from the middle East and Russia. The Americans developed synthetic rubber in World War II because the natural rubber plantations of Indochina had been captured by the Japanese.

There isn't the slightest doubt that new energy technologies from renewable sources can be developed, and that this will happen faster if access to cheap coal oil and gas is restricted. Wind power and solar photovoltaic power are two of the most promising possibilities. Solar hydrogen is the most exciting long-term possibility. None of these receive any significant public or private sector funding.

On the demand side, conservation can replace a much larger fraction of current energy consumption than the conservative establishment is willing to concede. In the replacement of fossil-fuels, however, positive incentives will be needed to overcome the natural advantages of invested capital and knowledge gained through experience. Yet only a tiny fraction of the world's energy R&D spending goes into the new and promising technologies. Most of it still goes into the discredited nuclear sinkhole, or into marginal technologies to help the existing energy establishment.

In the short run, radical new technologies will cost more than established ones. But in the long run they have far more potential to cut costs—and to do so without wrecking the environment. But the redirection of investment is not going to happen spontaneously or painlessly. If the industrial world is to achieve a sustainable relationship with the environment, major institutional changes will be needed, and steps in a new direction will have to be taken soon.

Part II, in the next issue, will discuss the economic basis for a new direction in the global energy economy.

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