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Carbon dioxide emissions and global warming

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Though not a unanimous view, a large number of scientists believe that unabated growth of greenhouse gas emissions might increase global mean temperature by two to five degrees centigrade, raise sea levels by 30 to 100 centimeters, and significantly alter weather patterns over the next century. These changes could threaten economic and social well-being through impaired agricultural productivity, regional water shortages, coastal flooding, and other impacts.

Policy discussions dealing with global warming have focused on controlling greenhouse gas emissions, particularly carbon dioxide (CO_2) emissions from fossil fuel combustion—the dominant contributor to the greenhouse effect. However, limiting CO_2 emissions to ameliorate climate change will be difficult.

Contributors to this issue of *Resources* examine the major issues that policymakers would face in controlling carbon emissions. Peter M. Morrisette and Andrew J. Plantinga explore the positions that various countries have taken on the global warming issue and the political and economic factors that may govern their willingness to support an international agreement to control emissions of carbon dioxide. In his analysis of one of these factors—the cost of CO_2 abatement—Joel Darmstadter scrutinizes the limitations of the two modeling approaches used to calculate the economic burden that a specific emissions limit would entail. Michael A. Toman and Dallas Burtraw concentrate on the question of equity in the sharing of this burden and on how fairness standards may evolve in negotiations to limit carbon emissions. Given the inability of traditional command-and-control measures to achieve emissions control at the least cost to society, Wallace E. Oates and Paul R. Portney appraise the relative merits of two incentive-based approaches to implementing greenhouse gas limits, both domestically and internationally. Finally, Pierre R. Crosson and Norman J. Rosenberg examine the often ignored role of adaptation to prospective climate change. In particular, they outline the nature and sequence of two kinds of adaptive response.

Research on climate change has been a growing activity at Resources for the Future since the establishment of its Climate Resources Program in 1987. The complex scientific, economic, and political issues surrounding climate change have stimulated many research efforts in other RFF programs. This special issue of *Resources* reflects this body of RFF investigation.

The first three articles that follow are based on research partially funded by the U.S.-Japan Foundation and the National Science Foundation under grant number DIR-9012507. ■

The global warming issue: viewpoints of different countries

Peter M. Morrisette and Andrew J. Plantinga

Once just a matter for scientific inquiry, global warming is now the subject of increasing political debate. The views of individual countries on what should be done about the problem range from commitment to stabilizing or reducing carbon dioxide emissions, which contribute to warming, to unwillingness to act. Because these positions are inextricably linked to domestic issues such as economic growth and technological capability, forging an international agreement on the control of greenhouse gas emissions will not be easy.

The sudden rise of global warming to prominence on the international political agenda is remarkable. In 1986 the global warming issue was of interest mostly to the scientific community, some environmentalists, and a handful of politicians. By the summer of 1988 the issue was nearing the forefront of international scientific and political discourse. In the United States and western Europe the public was being bombarded through the popular media (both print and television) with stories on global warming. Front-cover stories in *Time* and *Newsweek* underscored the potential for catastrophic consequences unless action was taken to control global warming. Elements of the international scientific, political, and environmental communities organized conferences and released statements expressing the need for governments to take action. World leaders such as former British prime minister Margaret Thatcher and Chancellor Helmut Kohl of Germany have taken a personal interest in the global warming issue. It became important in the 1988 U.S. presidential election and has been on the agenda of recent economic summits of the major industrial democracies.

In an effort to forge an international scientific consensus on the potential magnitude and impacts of global warming and what (if anything) to do about it, the United Nations Environment Programme and the World Meteorological Organization established the Intergovernmental Panel on Climate Change (IPCC). The recommendations by the IPCC, released at the second World Climate Conference (a meeting of 137 countries held in Geneva, Switzerland, in November 1990), included a call for international action to reduce emissions of gases that contribute to global warming (so-called greenhouse gases). In February 1991, representatives from over 100 countries met in Chantilly, Virginia, for the first of a series of meetings aimed at negotiating an international agreement on global warming.

The U.S. government approaches the control of carbon dioxide emissions with caution, believing that the costs will outweigh the benefits.

How can this heightened level of interest in the global warming issue be explained? Certainly the North American drought of 1988 and other unusual weather events around the world in recent years have sensitized the public here and elsewhere to the variability of climate. Other environmental problems such as ozone depletion, acid rain, and deforestation have raised public and political concern for the fate of the earth's environment. In addition, in the past two decades the scientific community has gained a much better understanding of how the earth's various natural systems—climate, the oceans, and the biosphere—interact, and how human activities can influence these systems. Together these factors provide at least a partial explanation for the high level of international interest in the global warming issue.

What can be explained more clearly are the positions that various countries have taken on the issue, and the political and economic factors that may govern the extent to which different countries will recognize the need for, and be motivated to support, an international agreement to control greenhouse gas emissions. Comparing the attitudes of different countries on the global warming issue provides some interesting insights on the prospects for such an agreement. At the risk of simplification, countries taking a position on an agreement can be broken down into four groups: developed countries advocating a cautious approach; developed countries pursuing a more activist approach; eastern European countries and the Soviet Union which, while concerned, are preoccupied with economic development and environmental degradation; and developing countries that cannot afford to and do not feel obligated to take action.

The cautious approach

The United States is the principal member of the group advocating a cautious approach (although other countries support part of the U.S. position). It maintains that not enough scientific evidence is available to justify potentially costly measures to mitigate emissions of carbon dioxide (CO_2). Nevertheless, it endorses preliminary actions such as establishing an international convention to devise a framework for dealing with global warming. It also supports the funding of research and the pursuit of what the Bush administration terms "no-regrets" climate change strategies. These are strategies, such as measures to conserve energy, that would produce im-

portant environmental benefits in addition to helping control global warming.

To a large extent, the U.S. position hinges on the belief that curtailing emissions of CO_2 would impose a substantial burden on the U.S. economy without providing significant corresponding benefits. This position is supported by the Council of Economic Advisers, which maintains that the stabilization of or reduction in CO_2 emissions is likely to be extremely expensive and could be more costly to the United States than to its major competitors. The U.S. perception of the magnitude and relative burden of costs to limit CO_2 emissions puts into perspective its policy to pursue no-regrets measures. Yet, to date, the United States has not explicitly pursued no-regrets climate change policies, but rather has identified existing policies (such as the U.S. obligation to phase out chlorofluorocarbons under the Montreal Protocol on Substances that Deplete the Ozone Layer) that also limit greenhouse gas emissions. The United States has been accused by nongovernmental organizations and some West European governments of using its emphasis on more research and no-regrets policies as a substitute for real measures to reduce CO_2 emissions. Yet the United States government believes that near-term action to stabilize or reduce CO_2 emissions is not yet warranted and is not in its best interest.

Internationally, the United States has been a major participant at climate change meetings, including those of the IPCC. However, it has generally found itself supporting a minority position on the content of many conference declarations. At the Ministerial Conference on Atmospheric Pollution and Climate Change held in Noordwijk, The Netherlands, in November 1989, the United States resisted efforts by many western European countries to specify targets and timetables for stabilizing and reducing CO_2 emissions. It rejected similar language at another international meeting held in Bergen, Norway, in May 1990, and at the second World Climate Conference. Rather than endorse specific CO_2 emissions targets, the United States supports the trading among countries of emissions reductions for multiple greenhouse gases—not just carbon dioxide—

Targets for Stabilizing and Reducing CO_2 Emissions from Present Levels

Country	Stabilization	Reduction
Australia		20% by 2005 [a]
Austria		20% by 2005
Canada	by 2005	
Denmark		20% by 2000
France	by 2005	20% by 2025
Germany		25% by 2005
Japan	by 2000 [b]	
The Netherlands		3% to 5% by 2000
New Zealand		20% by 2000
Norway	by 2000	
Sweden	by 2000	
United Kingdom	by 2005	

[a] All greenhouse gases.
[b] Stabilization of per capita emissions.

Climate change and sustainability

For many people, concern about the ecological and human effects of a changing climate is only part of a larger concern about the sustainability of economic and social progress given limited natural resources. While the concept of sustainability is somewhat unclear, it has assumed increasing prominence in national and global debates about environmental and natural resource issues since the publication in 1987 of *Our Common Future*, the report of the World Commission on Environment and Development (popularly known as the Brundtland Report). That report called for "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Most advocates of paying greater attention to sustainability take this phrase as a point of departure for understanding the concept.

How might climate change affect sustainability? Several possible problems have been identified by people who see climate change as a significant threat. At a local level, concerns are expressed about the economic productivity of specific natural resource systems, such as croplands, forests, and water. Concerns are also expressed about damages to local environmental resources, such as endangered plant and animal species, and to local human cultures. At a somewhat broader level, climate change could adversely affect the health and integrity of regional ecosystems such as large estuaries like the Chesapeake Bay in the United States. Economic productivity and environmental values could be harmed as a consequence, though the effects would be harder to trace given the complexity of the systems involved. Finally, threats at a very large, even global, scale could arise, such as changes in ocean currents. These potential impacts underscore the interconnectedness of the earth's natural systems—atmosphere, biosphere, and hydrosphere—and human society.

Supporters of greater concern for sustainability question the fairness of inflicting damages on the resources available to future generations. They even question the capacity of human society to continue in its present state if the worst possible impacts are realized. However, others note that there is a substantial and demonstrated capacity for human adaptation.

The importance of the sustainability issue is clouded by our limited knowledge of how climate change may affect ecological systems and how alterations of those systems may affect human well-being. Local effects on the economic productivity of specific resource systems may be the easiest to address. Threats to unique environmental resources or to larger-scale ecosystems may be harder to address and to anticipate.

Clarification of the linkages between climate change and sustainability deserves a high place in future climate research. Among other issues, those linkages will be explored in a program of research on global sustainability being developed at RFF.

Michael A. Toman
Peter M. Morrisette

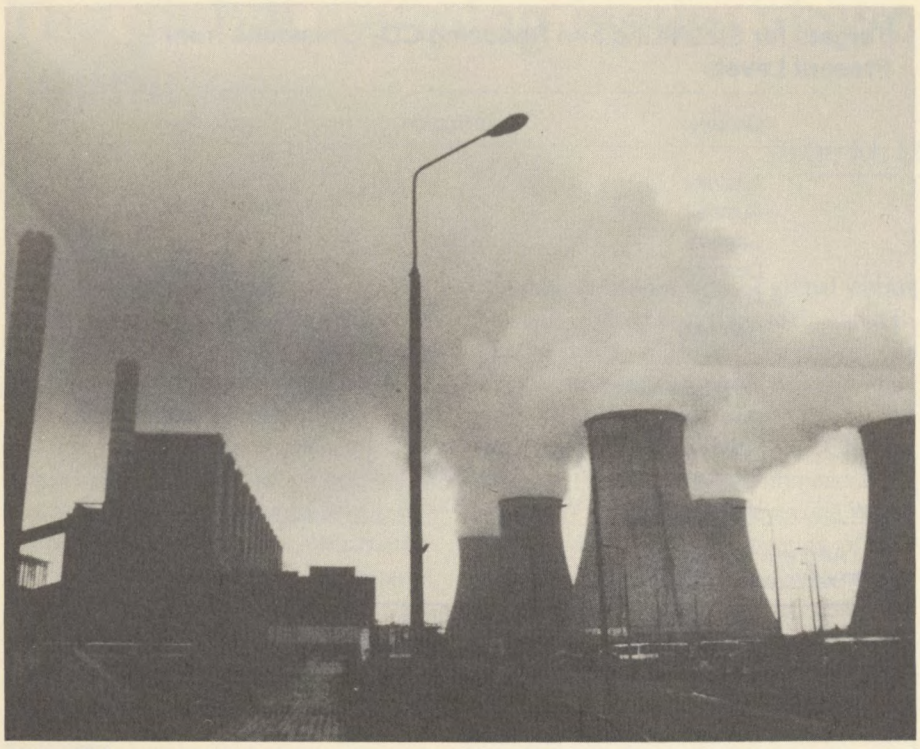

Photo courtesy of Richard A. Liroff - World Wildlife Fund

Poland's largest coal-fired power plant, Belchatow, has no controls for sulfur dioxide emissions. Given the task of reducing these and other emissions, eastern European countries may find it difficult to comply with an international CO_2 agreement.

believing such an approach will provide greater flexibility.

The activist approach

At one time, the United States found support for its position from other countries, particularly Japan and the United Kingdom (UK). Now, however, it is essentially alone, especially among member countries of the Organization for Economic Cooperation and Development (OECD). During the spring and summer of 1990, both the UK and Japan distanced themselves from the U.S. position. Both countries have announced targets for stabilizing greenhouse gases, joining many other OECD countries that have endorsed stabilization or, in some cases, reduction targets (see table, p. 3). This second group of countries, which advocates a more activist position, is made up mostly of OECD member countries, with Germany, Sweden, and The Netherlands taking leading roles. The United Kingdom, despite its more cautious policy statements, has also assumed a position of leadership.

The positions of the other OECD countries share several common features. These countries generally support the view that the scientific evidence points to a significant threat from climate change. Moreover, they feel that the benefits of averting the threat outweigh the costs of limiting emissions of CO_2 and other greenhouse gases. Some countries (for example, Germany and The Netherlands) are confident that plans to reduce CO_2 emissions can be applied without significant impacts on their economies, although Germany admits it has not conducted a thorough analysis. By themselves, however, any unilateral and even joint actions taken by these OECD countries would have little effect on atmospheric CO_2 content and could involve large costs for some OECD countries. Many countries state that their proposed efforts are intended to urge other countries to announce similar steps and support multilateral treaty efforts.

If the stabilization and reduction plans serve a primarily political function, their implementation may be compromised by other objectives. For example, Sweden revised a 1986 CO_2 stabilization target when it conflicted with plans to phase out nuclear power and limit future hydroelectric projects. The success of Japan's effort to stabilize greenhouse gases may depend on its ability to increase nuclear power capacity, a proposal strongly opposed by the Japanese people. In many OECD countries, CO_2 mitigation plans have only received cabinet-level approval and are "provisional"; there are no guarantees that they will be implemented. In addition, some plans are not as robust as they appear. For example, Germany's 25 percent emissions reduction figure is simply derived from an extrapolation of the declining trend in CO_2 emissions from 1970 to 1989.

However, even if reducing emissions is costly, many countries may perceive the cost of inaction to be greater. An obvious risk to The Netherlands is flooding from a rise in sea level. Germany, Australia, and Italy may also face acute risks from flooding, and some mountainous countries perceive threats from melting glaciers.

Some countries may even perceive benefits from widespread actions that make alternatives to fossil fuels more economical. For example, France, Sweden, and Germany have invested heavily in nuclear energy, hydroelectric power, and other alternative energy technologies and may foresee benefits from expanded markets for these technologies. Similarly, Japan's recent announcement of reduction targets for greenhouse gases may indicate its recognition of possible benefits from an international treaty, such as financial opportunities arising from the development of environmentally sound technologies.

Eastern European countries and the Soviet Union may find it difficult to reduce emissions while reforming their political and economic systems.

Because only a few countries are just now implementing rudimentary programs to control CO_2 emissions, it is difficult to judge the merits of the different positions taken by the various OECD countries compared with the position of the United States. At best, these positions represent

dutiful statements of intent, and it is likely that some are no more than political rhetoric. At this stage in the process, it seems likely that these countries are simply trying to position themselves for the next step—the negotiation of an international agreement on global climate change.

Countries unable to act

The radical political and economic changes recently occurring in eastern Europe and the Soviet Union offer hope, but also some concern, about the ability of these countries to address the global warming problem. The move toward democracy and market economies—at least in eastern Europe—has focused much attention on the failure of communist economic and political institutions to protect the environment. In addition, newly acquired political freedom in eastern Europe has made these countries eager to participate in international politics and to become more fully involved in European affairs. Yet given the enormous task of reforming their political and economic systems and of addressing their own environmental problems, eastern European countries and the Soviet Union may find complying with provisions of an international CO_2 agreement to be extremely difficult.

Thus these countries have not responded to the CO_2 issue with the same degree of commitment characteristic of many western European countries. For example, eastern European countries and the Soviet Union have not shown the same willingness as many western European countries to endorse unilateral action to stabilize or reduce CO_2 emissions. Confronted with the need to rebuild shattered economies, following through on commitments to reduce CO_2 emissions could be difficult for these countries. Nevertheless, even if unable to make commitments to reduce CO_2 emissions, these countries have professed serious concern about the global warming issue. In addition, eastern European countries and the Soviet Union have been well represented at recent international meetings and in the IPCC process; they also have strong scientific communities that are involved in climate change research.

Many developing countries feel that their contribution to global warming is being overstated and that the burden is on the developed world to deal with the problem.

Since the ability of eastern Europe and the Soviet Union to respond to environmental problems (both local and global) is limited by their current economic and technological capabilities, these countries have stressed the need for technological assistance from the West. Given the existing economic and environmental conditions, and the fact that these countries must institute reforms and address needs in both of these areas, financial and technological assistance from the West to eastern European countries and the USSR offers perhaps the most effective short-term response to limiting CO_2 emissions in these countries. Measures directed both at upgrading environmental standards and improving energy efficiency in these countries should in the long run help to reduce CO_2 emissions.

Countries unable and unwilling to act

The support of the developing countries will be essential to the long-term success of any international effort to reduce global greenhouse gas emissions.

Photo courtesy of The World Bank

In developing countries such as Bangladesh, it is impossible to separate the issue of economic development from the need to reduce CO_2 emissions.

These countries currently account for about 29 percent of global CO_2 emissions from the burning of fossil fuels. If the effects of deforestation are included—and estimates of these vary considerably—the developing countries may account for as much as 45 percent of total global carbon emissions. Equally important is the fact that the rate of increase in carbon emissions in the developing countries is much greater than that in the developed countries. Because of their rapid rate of population growth and industrialization, the developing countries will provide the bulk of new carbon emissions in the coming decades.

Gaining the full participation and support of developing countries for an international agreement on global CO_2 emissions will be an enormous task. As is the case in eastern Europe and the Soviet Union, it is impossible to separate the need for reducing CO_2 emissions in developing countries from other issues of economic, political, and social development, such as poverty, environmental degradation, and national debt. Perhaps more important, there is much distrust on the part of developing countries toward the developed countries. Many developing countries believe that their contribution to the global warming problem is being overstated, and they are suspicious of the international attention focused on deforestation and environmental degradation in the developing world. Developing countries feel that the developed countries created the problem and should therefore assume the burden of mitigating it.

In addition, many developing countries fear that they are in a no-win situation. They have neither the capacity nor the flexibility to mitigate CO_2 emissions or to easily adapt to changing climate conditions; thus, because of their less developed economies and limited capacity to respond to crises, they are likely to be among the countries most vulnerable to the impacts of climate change. Developing countries are also concerned that measures to control global CO_2 emissions will have a negative impact on their efforts to develop; these countries will find it very difficult, if not impossible, to sacrifice economic development for curbing global CO_2 emissions. In order for an international agreement on global warming to gain the widespread support of developing countries, it must address wider issues of environment and development.

Despite the feeling of purpose and commitment that many in the international community share for the global warming issue, attitudes, positions, and interests vary greatly. The success of ongoing international efforts to negotiate an international agreement on controlling global greenhouse gas emissions is by no means assured, yet neither is it impossible. Success, however, will depend on how the different stakes of nations can be dealt with in the negotiation process in an equitable and fair manner. ■

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Estimating the cost of carbon dioxide abatement

Joel Darmstadter

Cost will certainly be a factor in any efforts to limit emissions of carbon dioxide. Yet economists disagree when it comes to calculating the economic burden a specific limit will entail. Two different modeling approaches have yielded widely varying estimates. Given that evidence for substantiating these estimates is problematic, they must be viewed cautiously.

Many people have called for the stabilization or reduction of global carbon dioxide (CO_2) emissions, among them scientists attending the second World Climate Conference in Geneva, Switzerland, in late 1990. However, efforts to translate such goals into costs, while progressing, remain rudimentary. In a July 1990 draft report, the Inter-governmental Panel on Climate Change (IPCC) acknowledges this need for economic analysis.

How might one tackle the cost question? It makes sense to reckon CO_2 mitigation costs by comparing the real output of goods and services with and without CO_2 controls, since the value of economic output surrendered most nearly captures the cost to society of a CO_2 mitigation strategy. That output is commonly measured in terms of gross domestic product (GDP) or gross national product (GNP). Computing such losses in terms of GDP does not mean that trends or changes in that national-accounts measure are viewed as identical with trends or changes in social welfare. Nonetheless, such a macroeconomic calculation provides a broad indication of the economic burden of CO_2 containment.

The process by which restrictions on CO_2 emissions inflict a cost on an economy can be complex and hard to predict with precision. If a firm's compliance with CO_2 restrictions forces reliance on fuels whose production means higher real costs—that is, requires more employment of labor and investment of capital—the diversion of those factor inputs from other productive activities will lower the total output of the economy. Of course, numerous opportunities exist for attenuating the extent of a drop in GDP.

For example, constraints on the use of fuels containing carbon might instigate increased energy conservation, which may have a lesser economic penalty than a switch to a costlier alternative fuel. In principle, most modeling efforts allow for such tradeoffs in calculating the net cost to the economy of CO_2 abatement.

Needless to say, attention must be paid to the means and timing by which a specific reduction in global CO_2 emissions is to be achieved. At present there is no straightforward cost estimate for, say, a 20 percent reduction below the recently prevailing level of carbon dioxide emissions. The means employed (for example, taxes on carbon emissions or limits on emissions), the order in which different countries are supposed to comply (should the United States comply before China, or vice versa?), and the pace at which a policy is to be phased in (gradually or precipitously) will all affect such an estimate. Ideally, some sort of global least-cost calculation would emerge from analyses that account for these disparate factors. But it is important to recognize that models simulating the ramifications of a CO_2 abatement policy are stylized and highly imperfect representations of the complexity that characterizes the real world. The more such general equilibrium models attempt to track the pathways by which CO_2-limiting actions work their way through national and multinational economies—transmitting disruptive effects as well as inducing responses that cushion impacts—the more our need to appreciate the schematic nature of the modeling effort.

Picture some of the more obvious consequences of a country's decision to unilaterally tax the carbon content in the combustion of fuels. Demand for domestic coal would fall as consumers conserved or shifted to other fuels—the latter course possibly having a negative impact on industrial competitiveness in foreign trade. The demand for and subsequent rise in the price of low-carbon fuels might enhance both technological development and the potential of nonconventional energy sources (hitherto priced out of contention) to penetrate the market. In the meantime, the decline in the domestic coal market would promote the attractiveness of coal exports, complicating both the predictability of international economic adjustments and the extent to which the desired curtailment of CO_2 emissions might be undermined by the shipment of coal overseas. This example of the task that modelers face in trying to trace the net economic (and environmental) repercussions of CO_2 constraints is not intended to dismiss the utility of such analyses; there are few alternatives to relying on the insights they provide. At the same time, it is important to keep in mind any number of limitations inherent in such an effort—notably, weaknesses in data, uncertain behavioral phenomena, and, above all, the poor predictability of underlying economic trends many decades into the future.

Average Annual Percentage Rate of Change in Factors that Contributed to Global Growth in Carbon Dioxide Emissions, 1973–1987

Population	+1.74
GDP per capita	+0.99
Energy/GDP ratio	–0.59
CO_2/energy ratio	–0.39
CO_2	+1.75

Source: Yoshiki Ogawa, "Economic Activity and the Greenhouse Effect," *Energy Journal* vol. 12, no. 1 (January 1991), pp. 23–36.

Models simulating the impacts of a CO_2 abatement policy imperfectly reflect real world complexities; yet there are few alternatives to relying on the insights they provide.

Factors determining CO_2 emissions

A reduction or increase in the level of carbon dioxide emissions from the energy sector can conveniently be explained in terms of four key factors: population, GDP per capita, the energy/GDP ratio, and the CO_2/energy ratio. Other things being equal, slower population growth means less CO_2 released, while higher GDP per capita signifies more CO_2 emitted. The energy/GDP ratio is a measure of an economy's intensity of energy use, reflecting the structural, technological, and energy-use characteristics of a society. A falling energy/GDP ratio—brought about by improvements in the efficiency of electricity generation or automotive fuel economy, for instance—means less CO_2 emitted. The CO_2/energy ratio reflects the overall effect of a mix of energy sources and forms with varying carbon characteristics. Clearly, an important element in determining the costs of mitigating carbon dioxide emissions is the ease or difficulty of altering that mix away from carbon-intensive sources of energy such as coal, toward sources lean in or devoid of carbon, such as natural gas and solar and nuclear power. All the above factors must enter into analysts' attempts to probe the costs, as well as the technical feasibility, of CO_2 mitigation.

For historical perspective, it is worth noting the weight exerted by each of these factors in the growth of CO_2 emissions worldwide during the past several decades. Dr. Yoshiki Ogawa of the Japan Institute of Energy Economics has quantified the average annual percentage change in each during the years 1973 to 1987 (see table, p. 7). According to his calculations, downward trends in both the intensity of energy use and the carbon content of fuels were insufficient to overcome the effect of upward trends in population and per capita income on the growth of global CO_2 emissions. This suggests that, even with some future deceleration of population increase, if growth of CO_2 emissions is to be significantly slowed (let alone reduced) and economic growth (especially in the less developed countries) is to continue at

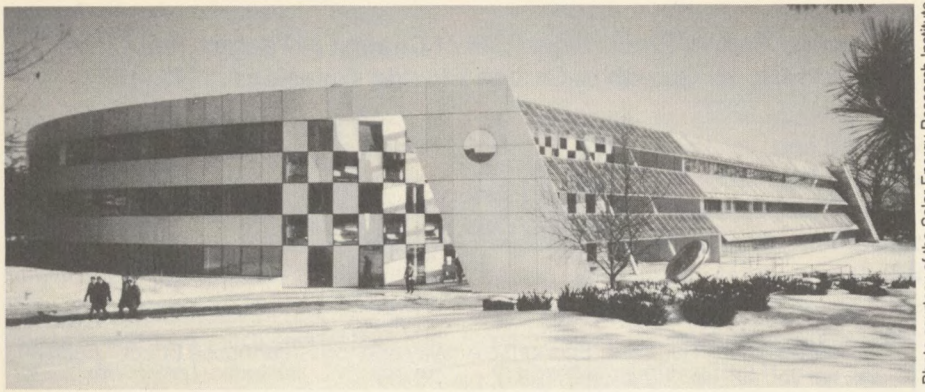

Photo courtesy of the Solar Energy Research Institute

This U.S. Department of Energy building in Illinois is designed to maximize energy efficiency. A modeling approach that focuses on such specific energy conservation opportunities reveals lower estimates of CO_2 mitigation costs than an approach based on aggregate economic modeling.

an adequate rate, a heavy burden would be placed on declining intensity of energy use and increasing recourse to noncarbon fuels. Thus, almost by definition, studies of the cost of mitigating carbon dioxide emissions focus, explicitly or implicitly, on one or both of these two factors as critical to the success of any CO_2 abatement effort.

Two kinds of economic modeling

Analyses of carbon dioxide mitigation strategies take one of two broad approaches: the "top-down" application of aggregate economic models and the "bottom-up" application of CO_2 abatement opportunities associated with specific energy uses in different sectors of the economy. Typically, the top-down approach involves the construction of stylized macroeconomic-technological models linking energy and the economy. In these models productive resources are reduced to broad classes of inputs (energy, capital, and labor), and, for time horizons many decades into the future, the values assigned to parameters and variables abound in uncertainty. This uncertainty spans key factors such as economic growth and its technological underpinnings; demographics; behavioral change that affects energy use; and the cost of energy resources and their substitutability with other resources.

The bottom-up approach stands in contrast to aggregate economic modeling by singling out the role of potential energy conservation. Analysis focuses on energy-using consumption and production activities, ranging from residential lighting to automotive transport to cogeneration of steam and electric power. Using the evidence gleaned at this level of disaggregation, analysts try to scale up their findings to ascertain the implications for the economy as a whole.

Although the point is frequently ignored or misunderstood, looking at CO_2 mitigation strategies from the perspective of energy conservation is not necessarily a logical alternative to, and need not be inconsistent with, economy-wide modeling. Rather, the bottom-up approach serves simply to emphasize one important component of the problem. Critics may contend that the top-down treatment of conservation is inadequate because of its aggregative character. But in principle enhanced energy efficiency is explicitly and necessarily treated in any analysis that has to incorporate the effects of price, income, and technological developments on both the energy demand and supply sides.

"Top-down" modeling shows that CO_2 mitigation exacts a significant price; "bottom-up" modeling reveals zero to small economic losses.

Some cost estimates

Nevertheless, the importance of the contrast in these approaches becomes apparent when one considers the sharply differing cost estimates for CO_2 mitigation that they yield. Alan Manne of Stanford University and Richard Richels of the Electric Power Research Institute have used the top-down approach to estimate the cost of limiting global CO_2 emissions to about 18 percent above the present level throughout most of the twenty-first century. (The present level is estimated to be about 6 billion metric tons annually, excluding the effects of deforestation.) They have calculated that such a limit would necessitate a carbon tax rising to approximately $250 per ton of carbon emissions. (Based on the respective carbon content of coal and oil, the carbon tax on coal would rise to roughly $150 per ton and on oil to $30 per barrel.) That limit could also exact economic penalties ranging from 3 to 10 percent of the gross domestic product in various countries around the world. Using the top-down approach (based on a number of underlying studies), William Nordhaus of Yale University arrived at comparable findings.

The Congressional Budget Office also used the top-down approach to arrive at near- and very-long-term cost estimates for the United States alone. Its study found that a tax of $10 per ton of carbon emissions, rising to $100 per ton during the years 1991 to 2000, would stabilize the level of U.S. carbon dioxide emissions at recent levels by the year 2000 and reduce them to more than 20 percent below these levels by 2100. Throughout the next century, annual levels of U.S. economic activity would hover at about 1 percent below the baseline path otherwise assumed to prevail. Since under that baseline path CO_2 emissions would grow far less rapidly in the United States than in other parts of the world, U.S. economic losses for a specified percentage reduction in CO_2 emissions from prevailing levels would be much more modest than, say, in the Soviet Union, China, and the less developed countries.

For the world as a whole, top-down modeling work clearly shows that CO_2 mitigation exacts a significant price. In sharp contrast, an analysis of CO_2 mitigation costs based on the bottom-up approach reveals that zero to small economic losses—depending on the level of mitigation specified—would be incurred. William Chandler of Pacific

Northwest Laboratories directed eight country case studies that focus on possible energy efficiency improvements during the years 1985 to 2025. He found that a potential exists for the Soviet Union, several countries in eastern Europe, and key member countries of the Organization for Economic Cooperation and Development to substantially reduce absolute emissions of carbon dioxide with virtually no forfeiture of economic output. Even if anecdotal and selective, Chandler's examples of economic waste in energy use are telling: gross inefficiency in Poland's combined heat-and-power systems; leakages in the Soviet Union's gas distribution network; and instances of "sub-optimal" energy use in U.S. buildings and transport. Summing up the eight case studies, Chandler suggests that stabilization of emissions would entail zero economic costs through 2005 and that a 20 percent cut in the present level of carbon dioxide emissions would inflict losses no higher than 0.1 to 0.5 percent of the gross domestic product in the countries studied.

How costly is costly?

What is one to make of modeling approaches that yield such different estimates of CO_2 mitigation costs? Evidence substantiating either the high cost estimates (resulting from the top-down approach) or the low ones (resulting from the bottom-up approach) remains far from satisfactory. In the case of the top-down approach, technological advances—facilitated by aggressive research and development and the elimination of market frictions (such as the failure to price electricity at replacement cost)—might make substitutes for carbon-based fuels much less costly (and thus less burdensome on economies) than Manne and Richels hypothesize. For example, their estimate of the cost at which a non-carbon supply source, such as solar energy, would enter energy markets is a very high $20 per million British thermal units (Btus), an order of magnitude higher than prevailing fossil fuel costs. In addition, Manne and Richels allow for a rather low rate of autonomous technological improvement—that is, the inherent and persistent tendency toward enhanced energy efficiency independent of improvement induced by relative price change.

In the case of the bottom-up approach, do Chandler's examples of the potential for conservation truly meet an economic feasibility test such that trends in the economic performance of individual nations can remain undisturbed for many decades? In other words, how much energy can be saved and to what level can CO_2 emissions be reduced at zero cost? The perennial question of what combination of market imperfections and public policy deficiencies significantly inhibit conservation initiatives takes on renewed importance as global climate change reinforces concern about other problems associated with energy use, such as localized air pollution, vulnerability to disruptions in the world oil market, and preservation of ecologically sensitive land and marine resources.

Both the high and low estimates of CO_2 mitigation costs are based on evidence that is far from satisfactory.

It remains to pose the question: How costly is costly? A country able to achieve a targeted level of CO_2 emissions by the end of the twenty-first century under conditions in which its GDP is never more than, say, 3 percent below the trend line will show an average annual percentage growth rate in GDP indistinguishable from that trend line if that rate is not calculated beyond one decimal point. If, in that sense, the cost seems inconsequential, those pointing to the cumulative volume of goods and services forgone over 100 years will not be as cavalierly dismissive. In a world of competing demands for scarce resources, there must be a clear justification for committing "just" 3 percent of a country's GDP to any one cause. It takes only thirty-three causes, each claiming 3 percent of the GDP, before 99 percent of the economic pie has been spoken for!

In that light, society's willingness to bear CO_2 mitigation costs must at some point be conditioned both by alternative response strategies—for example, adaptation—and, more elusively, by perceptions of the harm that an unfettered increase in global warming would induce. Given the potentially large costs societies will bear for serious constraints on CO_2 emissions, mitigation strategies must have some claim to cost-effectiveness if they are to have any chance of being accepted. They must also make provisions for an equitable sharing among nations of the burden of mitigation costs. ■

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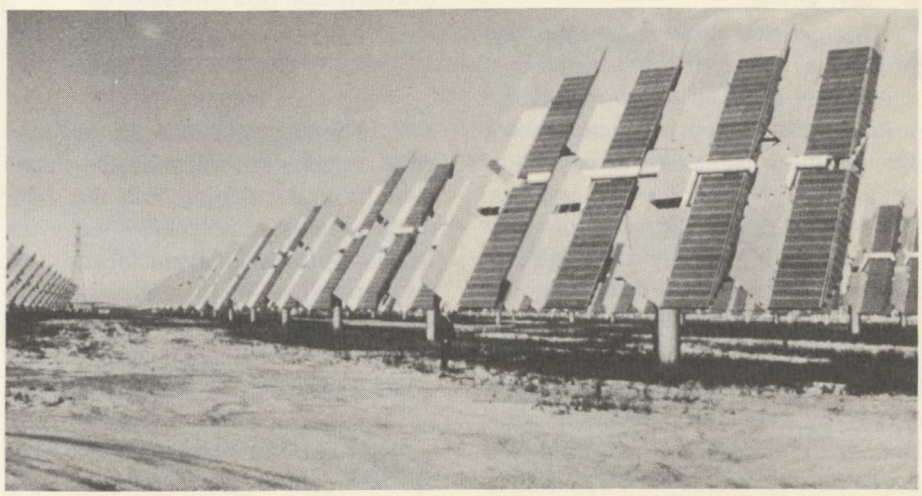

Photo courtesy of the Solar Energy Research Institute

These photovoltaic arrays in Carrisa Plains, California, transform the sun's power into electricity. With technological advances, substitution of carbon-based fuels by solar energy might be less costly than some estimates suggest.

Resolving equity issues in greenhouse gas negotiations

Michael A. Toman and Dallas Burtraw

One issue of fairness likely to arise in negotiations to control emissions of greenhouse gases is the equitable distribution of costs. Simple cost-sharing rules lessen the complexities of determining such a distribution, but cannot alone guide the negotiation process. Strategic issues such as the relative urgency with which parties view the need for an agreement and the perceived benefits accruing from it will influence the evolution of fairness standards. With no clear precedent for allocating costs fairly, consensus on procedural matters, such as the role of nongovernmental organizations in the negotiations, is needed to smooth the way for an agreement.

Fairness is a key aspect of any international agreement. An agreement among sovereign states is fundamentally different than the resolution of a domestic dispute, in which parties have recourse to the force of law. International undertakings will not induce compliance unless the decision makers in each participating country, and the key interest groups influencing those decision makers, believe that national interests are being adequately served.

This general observation about the importance of equity in international agreements takes on added importance in the context of recent negotiations about limiting global emissions of carbon dioxide (CO_2) and other greenhouse gases. The costs of abating these emissions are quite uncertain but likely to be high (see "Estimating the cost of carbon dioxide abatement" in this issue). The potential benefits of abatement are even more controversial, and likely will be reaped mostly by future generations. In addition, individual nations approach the greenhouse gas issue with very different attitudes about what should be done (see "The global warming issue: viewpoints of different countries" in this issue). Generally, wealthier developed countries profess a greater willingness to take action (though the U.S. position favors more modest abatement efforts and more research). In contrast, developing countries and members of the former East European bloc are more concerned with their immediate development and environmental problems. These differences in attitude increase the burden negotiators face in seeking an outcome that participants can embrace as fair.

Possible rules for sharing costs

To simplify the process of negotiation, negotiators will attempt to seek out rules of thumb for which there are precedents in other negotiations and around which they may naturally coordinate their individual actions. In addressing the issue of how to equitably distribute the costs of limiting emissions of greenhouse gases, negotiators will look for simple focal points for sharing costs that command widespread acceptance as having fair outcomes while simultaneously being compatible with the interests of individual parties.

Ability to pay and polluters pay are two of the possible rules for the sharing of costs to reduce greenhouse gas emissions.

One such rule might be an equal percentage reduction of emissions. Under this rule, each country reduces its emissions by the same fraction, and each bears the full cost of that reduction. Each country's share of total abatement costs will depend on the particular ease or difficulty of abatement in that country. For example, countries heavily dependent on fossil fuels will find it more difficult to limit emissions.

Another rule negotiators might use focuses on ability to pay. Under this rule, once the responsibilities of individual nations for emissions reduction are established, costs are shared according to income levels in each country. To implement the rule, transfer payments from richer to poorer countries would be needed to equalize the relative cost burdens.

A third rule is based on the principle that polluters pay. Under this rule, once the responsibilities of individual nations for emissions reduction are established, costs are shared according to the amount of greenhouse gases they emit. Developed countries with higher total emission levels would bear more of the costs than developing countries with lower emissions, but developing countries would bear a rising share of the costs over time as their economic development raised their share of global emissions.

A fourth rule is based on the idea of a natural right to emit in which the capacity of the atmosphere to absorb greenhouse gases is treated as a common property resource to which all people should have access, regardless of income or other circumstances. Implementing this rule might entail the allocation of emissions rights to nations according to population. In allocating these rights, adjustments might be made for the industrial countries' heavier past use of the atmosphere's absorptive capacity. Provisions might also address the higher population growth rates in developing countries so as not to reward a population explosion. The effect would be to place greater responsibility on developed countries either to restrict emissions or to purchase the unused emission rights of developing countries. Provided that they

did not exceed their own emissions limits, the opportunity to collect revenues from these transactions would give developing countries a financial capability and an incentive to restrict the growth of their own emissions.

Each of the above fairness rules has some precedent. Equal-percentage rules frequently arise in international undertakings in which uncertainties or institutional constraints limit the direct sharing of costs. Ability-to-pay considerations underlie the creation of financial and technical assistance for developing countries to phase out ozone-destroying chlorofluorocarbons (CFCs). The polluter-pays principle underlies many domestic rules concerning liability for environmental damages and is the stated means for addressing transboundary pollution issues within the Organization for Economic Cooperation and Development. Finally, the idea of common-property resources is confronted whenever a resource is held to be a common heritage of mankind, as in negotiations over the Law of the Sea Treaty.

Can simple rules guide negotiations?

The number of possible focal points, including others not listed above, illustrates the difficulty of finding simple rules of thumb for coordinating the sharing of costs. The diversity of rules would not be a major problem if the rules had similar consequences. However, an illustrative comparison of the outcome of implementing ability-to-pay and polluter-pays rules to limit CO_2 emissions suggests that this is unlikely to be the case (see table, p. 11). According to this comparison, the polluter-pays approach would cost the developing countries a larger share of their national income than the ability-to-pay approach. Although their emissions are low relative to those of the industrial world, their income is even lower relative to that of developed countries. Conversely, industrial countries outside North America, with relatively high incomes and lower CO_2 emissions than the United States, would face lower relative costs under the polluter-pays approach than under the ability-to-pay approach.

A comparison of the outcome of these approaches with that of equal-percentage and common-property approaches is hampered by a lack of information on abatement costs in different countries and regions. Nevertheless, some general observations can be made. Equal restrictions on emissions relative to current emission rates might have consequences similar to a polluter-pays approach if abatement costs were to be similar across countries. However, this is almost surely not the case. In many developing countries abatement costs might be low relative to costs in industrial countries (albeit high relative to income in developing countries) because of low levels of energy efficiency. (An important exception might be China, which has low energy efficiency but vast coal reserves that could be greatly devalued by an effort to limit greenhouse gases.) Thus the equal-percentage approach might yield an outcome somewhere between the polluter-pays and ability-to-pay approaches for many regions of the world.

In sharp contrast, assigning emissions rights based on population under the common-property rule would put a large share of the abatement burden on the developed countries. For example, with a global emissions reduction target of 20 percent and rights allocated according to population, the developed world would have to cut emissions by more than 70 percent (more than 80 percent in the United States) or borrow emission rights from the developing world. Given realis-

Comparison of Income-Based and Emissions-Based Cost-Sharing Criteria for Carbon Dioxide Reduction

	Regions			
Cost-sharing criteria	North America	Other industrial countries	Soviet Union/ eastern Europe	Developing countries
Equal cost share relative to total pre-control income				
Total cost (U.S. 10^9)	92	94	62	56
Per capita cost ($/person)	340	190	150	16
Cost relative to pre-control CO_2 emissions ($/ton)	58	78	44	35
Cost relative to pre-control income	0.02	0.02	0.02	0.02
Equal cost shares relative to total pre-control emissions				
Total cost (U.S. 10^9)	82	62	72	82
Per capita cost ($/person)	300	120	170	22
Cost relative to pre-control CO2 emissions ($/ton)	51	51	51	51
Cost relative to pre-control income	0.02	0.01	0.02	0.03

Note: The comparisons are based on an overall cost burden equal to 2 percent of 1987 gross world product. The figures given here are illustrative and should not be viewed as precise estimates.

tic estimates of the industrial countries' marginal abatement costs, which would affect the price of emissions permits, the financial transfers to developing countries would be so large that it is difficult to believe developed countries would accept this approach.

Strategic aspects of negotiations

Disparities in outcome among fairness rules, the lack of clear precedent for any one approach, and the wide variance observed in national attitudes toward greenhouse warming make it unlikely that simple rules of thumb alone can successfully guide the negotiation process. In the absence of a clear focal point that could serve to coalesce the expectations of negotiators and guide their actions, strategic aspects of the negotiations will likely play a heightened role in determining the outcome. Furthermore, if an agreement is achieved, it would serve as an important precedent for the future.

Standards of equity will be shaped by how parties view the need for and benefits of an agreement, and by possible options outside an international agreement.

Thus strategic and procedural aspects of negotiation can be viewed as essential to the evolution of a commonly shared standard of equity that must accompany an international agreement.

One factor of strategic importance is the relative urgency with which participants view the need for agreement: those who see delay as costlier will be more willing to accept a larger cost burden for constraints on emissions of greenhouse gases, other things being equal. A second strategic factor is how different parties view the risk that negotiations might be unsuccessful; again, those who perceive larger risks will be more willing to accept a larger cost share.

As stated previously, perceptions of both the benefits and costs will be important to the ability to reach an agreement. National populations that perceive themselves as less threatened if global warming is not slowed will be less inclined to absorb a major cost burden. National perceptions of global warming are often tempered by more immediate financial concerns or by doubts about the ultimate severity of the problem. As long as nations view the cost of failing to reach agreement in this way, concrete agreements to constrain emissions of greenhouse gases may be slow in coming.

Another important strategic factor is the possible existence of options outside an international agreement that different participants could resort to if negotiations were unsuccessful. For instance, many nations may have the option of pursuing unilateral strategies for adapting to climate change—such as the construction of sea walls or the introduction of new agricultural practices—that they could pursue in the absence of or even in addition to a multilateral agreement. (For a discussion of adaptation measures, see "Adapting to climate change" in this issue.) Nations are unlikely to accept negotiated outcomes that are more costly than unilateral adaptation measures, so these outside options will serve as constraints on international agreements.

In the absence of a clear precedent for negotiations, standards of equity also will be shaped by the negotiating process itself—the opportunities for communication, the emergence of leaders, and the extent to which the process is seen to be cooperative problem-solving rather than just bickering over shares of a burden. And, to some degree, the actions of negotiators might be motivated by a sense of altruism or global responsibility. However, the limits of altruistic motives are highlighted by debates over current levels of foreign aid. Representatives from some developing countries have been adamant that climate-related income transfers not compete with other aid for purposes they view as more urgent. At the same time, there appears to be little sentiment within wealthier countries to increase current foreign aid solely on altruistic grounds. Thus the prospects for reaching an international accord on climate change may be best served by the design of an agreement that is motivated by the material self-interests of the signatories, rather than altruism.

Although simple fairness rules may not be able to resolve climate negotiations, they nevertheless will influence how negotiators view the opportunities for reaching agreement. The negotiating process must be seen as a two-level undertaking, involving both interactions among negotiators and interactions by negotiators with their national societies and groups. Domestic public opinion will be an important constraint on the actions of negotiators. Understanding of such a complex process remains limited, both in theory and in practice. However, public perceptions of fairness may hinge on issues of procedure as much as on those of allocation. If the process of negotiations is perceived as fair, the prospects for agreement will be heightened.

Perceptions of fairness may hinge on issues of procedure as much as on those of allocation of burden.

Implications for negotiations

With manifold uncertainties surrounding the issue of greenhouse gas emissions and global warming, and with only weak precedents to guide nations toward an equitable allocation of responsibility for the costs of mitigation, questions of procedural equity emerge as a source of greater concern. The perceptions of the general population are important in this regard, and one goal of the negotiation process should be to educate and involve disparate interest groups. Thus the practice of involving nongovernmental organizations in the negotiation process will be important in facilitating eventual agreement and implementation. Government negotiators and other participants need to establish a negotiating process that provides for consideration of a variety of attitudes and proposals while uncertainties are being

reduced and fairness standards are being forged. Otherwise it is difficult to envision widespread national adherence to the negotiating process itself, let alone any substantive requirements emerging from the process.

A focus on procedural fairness should be embodied in the current pursuit of a framework agreement for limiting CO_2 emissions and other contributions to global climate change by human activities; such an agreement should set the stage for subsequent protocols requiring specific actions (such as a stabilization or reduction of CO_2 emissions). Two issues that may be especially important to consider in developing a framework agreement concern the linkage of global warming to other issues and the mechanism that would govern international cost redistributions. Rules need to be established that delimit the ability to couple an agreement to limit the emission of greenhouse gases to other issues, such as foreign development aid, trade barriers, population, and so forth. Decisions should also be made about the options available for cost redistribution—direct financial aid versus aid tied to a target such as energy efficiency. Prior agreement on such procedural matters could help smooth the way for substantive limits on emissions of greenhouse gases in the future. ■

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Economic incentives for controlling greenhouse gases

Wallace E. Oates and Paul R. Portney

An emissions tax or system of transferable emissions permits to limit carbon emissions could significantly lower the cost of efforts to deal with global warming. In a domestic setting, preference for one or the other instrument depends on whether it is more desirable to have control over the level of emissions or over costs to limit emissions. The choice is more difficult in an international setting. However, in that setting the political economy may favor a tax because it is easier to adjust than a permit system.

Limiting emissions of carbon dioxide and other greenhouse gases could be very expensive. If control measures are to be taken, serious thought should be given to so-called incentive-based (or IB) policies because of their cost-saving potential. Two such IB policies are particularly attractive—emissions taxes and transferable emissions permits.

Either approach could be used at the national or international level. For instance, nations might jointly negotiate worldwide limits on greenhouse gas emissions, then introduce taxes or marketable permits to meet their individual obligations. Alternatively, nations might agree to use economic instruments at an international level—a global emissions tax or a worldwide market for emissions permits. Unlike a command-and-control (or CAC) approach to limiting emissions, in which a national or international authority establishes very detailed pollution-control measures for each of a large number of sources, IB policies harness the power of self-interest to protect the environment. In so doing, they can reduce emissions at least cost to society, thus freeing up resources for other pressing problems.

The cost-saving capacity of IB approaches has both a short-run and a long-run dimension. In the short run, when technology is more or less fixed, emissions taxes or marketable permits would confront sources of greenhouse gases with a price for their pollution—either they would pay a tax for each ton discharged or they would have to acquire a permit (a costly permit). In either case, sources that could reduce a ton of emissions at a cost less than the per-ton tax or permit price would elect to do so since they would save money as a result. Sources finding emissions control more expensive on a per-ton basis than the tax or permit price would not reduce emissions. Thus, without any direction from a central authority, emissions control would automatically be concentrated at the sources where it is least expensive.

Over the longer term, IB policies would provide powerful incentives for research on and development of new technologies to limit greenhouse gases. Polluters could reduce the taxes they pay—or the amount they spend on permits—by finding cheaper and more effective ways to reduce their levels of emissions. Thus taxes or marketable permits would effectively harness the profit motive, both in the short run and the long run, to work on behalf of pollu-

Emissions permits have been favored in the United States because they raise less political opposition than a tax, and regulators are comfortable with them.

tion control. Several studies have found very large cost advantages for IB policies, with savings amounting to as much as 90 percent of the cost of a CAC approach that produces the same emissions reduction.

Comparing taxes and permits

Despite the fact that emissions taxes and marketable permits both confront sources with a price for their emissions (and, in so doing, result in cost-minimizing outcomes), these two approaches have some important differences in a policy setting. These differences explain why legislators and environmental regulators in the United States have favored marketable emissions permits over emissions taxes. Under the Clean Air Act Amendments of 1990, for example, reductions in sulfur dioxide emissions from coal-fired power plants will be achieved through a system of marketable permits. And under the U.S. Environmental Protection Agency's Emissions Trading Program, attacks on urban smog and other traditional air pollution problems have included limited use of tradeable emissions permits.

One advantage of the permit approach is that it gives regulators direct control over the quantity of emissions. This is important since environmental laws typically call for specified levels of pollutant emissions or ambient concentrations. In addition, the permit approach can offer a way around one of the political obstacles to emissions taxes—namely, that if all emissions are taxed, sources could face very large tax liabilities for emissions that in the past have been free. Of course, this would also be true if the government decided to "confiscate" all heretofore permitted emissions and chose to auction them off to the highest bidder. But there is another way a permit system could be set in motion. The regulator could distribute the desired number of permits free of charge to existing sources in proportion to their previous emissions and then allow free trade in the permits between any buyer or seller. The granting of valuable assets like permits to existing sources would obviously engender much less opposition from emitters than would the levying of a tax.

A permit system allows control over the level of emissions but may impose excessive control costs on emitters, a danger that could be avoided with a tax.

Finally, marketable discharge permits have been more readily accepted than emissions taxes simply on the grounds of familiarity. Regulators have experience and are comfortable with discharge permits, which are the staple of CAC regulation. It seems less radical to make these permits transferable than to junk them altogether in favor of untried emissions taxes.

Experience with the Emissions Trading Program does raise one potentially serious problem with the permit approach—the operation of permit markets. In theory, brisk buying and selling among many parties in the permit market establishes a competitive price. In practice, however, the number of potential participants in these markets is often small and certain large sources may be able to exercise monopolistic price-setting powers or even use their control of permits to restrain competition in their respective industries. Either way, this would foil the purpose of the permit market; emissions taxes, on the other hand, are not prey to this potential shortcoming. There the authority sets the tax and all emissions are subject to it. New sources of greenhouse gases would be free to enter any market so long as they paid the emissions tax.

It seems unlikely that lack of competition would be a significant problem in a market for permits for a greenhouse gas like carbon dioxide, however. In contrast to the limited scope of emissions trading

Photo courtesy of the Ohio Edison Company

In the United States, regulators have preferred a permit system over taxes to control emissions. For example, reductions in sulfur dioxide emissions from coal-fired power plants like this one in Toronto, Ohio, will be achieved through a system of marketable permits.

so far, a domestic market for carbon emissions permits would presumably be national in scope. In such a setting, there should be many active buyers and sellers, and competitive conditions should prevail.

Policy choice given uncertainty

When the benefits and costs of emissions control are uncertain, as they are sure to be, the choice between emissions taxes and transferable emissions permits is more difficult to make. Errors in setting the rate at which emissions are taxed or in determining the quantity of permits to be issued can have very different consequences.

Consider a setting in which disastrous environmental consequences would ensue if pollutant concentrations were to exceed some threshold level. If the environmental authority set an emissions tax too low, emissions might exceed the threshold level. In this case it would be better for the environmental authority to employ a permit system under which it could ensure that emissions stay below the danger level.

Under an alternative setting, however, environmental damage from additional emissions does not increase significantly, but control costs do. In fact, most studies indicate that—regardless of the pollutant in question—beyond a relatively constant range the marginal cost of additional control begins to increase sharply. Here, setting an emissions limit that is too tough (allowing too few permits) could impose high control costs on most sources. With an emissions tax, this danger is avoided because sources could always opt to pay the tax and avoid the more costly control measures.

Which, then, is the better policy instrument—an emissions tax or a system of transferable emissions permits? The choice would be clearer if we had a better fix on the damages associated with greenhouse gases and the costs of controlling them. With respect to damages, most projections seem to suggest that they would increase gradually as greenhouse gases accumulate in the atmosphere. However, there are fears that, beyond some threshold, global warming could suddenly become self-reinforcing and increase rapidly. If so, the preferred policy instrument clearly would be one that allows firmer control over the level of emissions—namely, a permit system.

On the other hand, there are good reasons to believe that the marginal costs of reducing emissions of carbon dioxide and other greenhouse gases will rise—and probably rapidly after some point. In setting purely quantitative targets for emissions reductions, as in a permit system, there may be a danger of incurring much higher costs than envisioned at the outset. This danger could be avoided by levying an emissions tax. A substantial tax could induce all the control activities that are reasonably affordable. Although the exact size of the emissions reduction would be uncertain, a tax would protect against the huge costs that would be incurred to achieve some (perhaps quite small) additional reductions in carbon emissions.

Given the certainty of rising emissions control costs, the use of an emissions tax appears preferable, at least for the present.

An international emissions tax or permit system would be hampered by the lack of an entity to enforce global emissions policies.

If, however, scientists find that there are critical threshold levels of atmospheric CO_2 and other gases, a system of transferable emissions permits would look more attractive.

Policy choice in a global setting

On an international scale, the choice of policy instruments for limiting emissions of greenhouse gases becomes more complicated. A realistic appraisal must address two problems. First, effective use of emissions taxes or transferable emissions permits requires a certain minimum level of administrative and technical sophistication (with regard to monitoring, for instance), which may be lacking in some of the developing countries. Second, there currently exists no international agency with the power to ensure compliance with global policies. This presents a particular problem in the global trading of emissions permits, for which an entity like a domestic court system is needed to enforce property rights over the permits and compel adherence to contracts to trade these rights.

An additional problem must be addressed to make emissions trading feasible on a global scale. It is difficult to envision a competitive international market in permits because so many participants would come from nonmarket economies and because some participants from market economies, such as regulated or nationalized electric power companies, could have distorted incentives. To make a global market for carbon dioxide permits competitive, Michael Grubb of London's Royal Institute of International Affairs proposes that permits be initially vested in governments for use by their national emitters, rather than in private hands. The primary purpose of Grubb's proposal is to address the distribution of the responsibility and cost for emissions control among nations, not (as with the domestic permit market) to achieve an internationally cost-effective allocation of control efforts. Grubb further suggests allocating permits to each country in proportion to its adult population; industrial countries finding themselves with fewer permits than current CO_2 emissions could then "rent" permits from any developing countries finding themselves with a surplus, provided the proceeds were used by the latter to mitigate global warming. Domestic control policies (permit trading, taxation, or CAC measures) would be needed in the industrial countries to satisfy their national obligations for greenhouse gas limitations.

International exchange would establish market prices for permits that developed countries would be willing to pay when their own mitigation costs were higher. However, there is no reason to believe that the resulting distribution of emissions control efforts would be cost-effective, because governments lack the information possessed by individual emitters to exhaust all gains from trade. Instead, the main accomplishment of Grubb's program would be to provide an economic incentive for developing countries to participate in mitigation efforts, since their failure to

do so would cost them revenue from permit sales. However, Grubb's formula for the initial distribution of permits may place an intolerably high cost burden on the industrialized world (see "Resolving equity issues in greenhouse gas negotiations" in this issue).

Another proposal for international emissions control—one that favors a tax approach—has been offered by Darius Gaskins of Harvard University and Bruce Stram of the Enron Corporation. Their proposal calls for agreement on a tax rate applicable to carbon emissions from member nations of the Organization for Economic Cooperation and Development. The proceeds of the tax would be earmarked for developing countries to use in limiting greenhouse gas emissions. The intent and focus of this proposal are similar to Grubb's. The main differences are in the choice of instrument and in the intensity of control—Gaskins and Stram would start out with much more modest incentives for greenhouse gas limits.

Grubb contends that tax systems vary widely among nations and often include subsidies (some hidden), making it hard to harmonize tax policy on an international scale. On the other hand, a tax is a highly visible sign of the cost of emissions control programs—and a flexible one. The tax rate could presumably be adjusted over time if either more or less effort were required to contain carbon emissions. Moreover, the tax approach provides protection against decisions that could prove overly costly, since emissions sources have the option of paying the tax rather than introducing further control measures. Once permits are issued and traded, on the other hand, the cost of curtailing carbon emissions becomes hidden in product prices and is less apparent to the public and its representatives. This may bias the policy process in favor of excessive controls.

Entitlements granted by permits also tend to generate vested interests, making adjustments in the supply of permits difficult to bring about. For example, if new research convinces us that climate change is not the serious problem it is now believed to be, we would want to increase the number of permits. But existing permit holders (like those owning taxi medallions in New York City) would object, since this would devalue the permits for which they may have paid a sizable sum. Conversely, buyer resistance could scuttle reductions in the number of permits. For these reasons, some contend that the political economy of the situation favors taxes over permits.

A final point bears mention. Any truly cost-effective approach to preventing global climate change must encompass all radiatively active gases, not just carbon dioxide. In this regard, neither taxes nor marketable permits have a distinct advantage, either as unilateral or multilateral instruments. Under a tax regime, the tax on carbon emissions could be set first, with appropriate tax rates established for the other greenhouse gases on the basis of their relative contribution to warming. If a gas were ten times more harmful than CO_2 on a per-ton basis, the tax rate would be ten times that for CO_2. Under a permit system, the terms of trade could be made to depend on radiative potential. For example, to emit one ton of the more potent gas, 10 carbon permits would have to be acquired. As scientific information accumulated about relative potencies, tax rates or trading ratios could be adjusted.

This need to account for other radiatively active gases represents an added complication to any regulatory approach. But it should be considered because it is likely that the optimal preventive strategy will include a number of measures directed at greenhouse gases other than carbon dioxide. This observation heightens the importance, and the challenge, of harnessing economic incentives to limit global warming. ■

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Adapting to climate change

Pierre R. Crosson and Norman J. Rosenberg

Adaptation and mitigation are sometimes treated as mutually exclusive approaches for dealing with global warming, but it is now acknowledged that they can be pursued jointly and that there are tradeoffs between them. A critical policy issue is the determination of which mix of adaptation and mitigation measures will maximize the benefits of efforts to reckon with climate change. Unfortunately, much less is known about how to adapt to that change than how to mitigate it. Despite this fact, the developed and developing countries have a mutual interest in devising adaptive responses, even if agreement on mitigation strategies remains elusive.

Photo courtesy of Norman J. Rosenberg

Scientists are experimenting with different types of soybeans to determine which ones are best adapted to specific climate conditions.

There is now reasonable scientific consensus that the continued loading of the atmosphere with radiatively active trace gases such as carbon dioxide, methane, nitrous oxide, chlorofluorocarbons (CFCs), and other gases will cause the troposphere (the lower portion of the atmosphere) to warm. As a consequence of this warming, climatic conditions throughout the world would change; less certain is the nature of these changes and where they would occur. Still less certain are the rate at which the atmosphere might warm, the attendant rate of change in climatic conditions, whether transient climate changes will occur (for example, cooling in a locale before it warms), and whether climate might change so that the frequency and severity of extreme events—such as droughts, storms, floods, and freezes—might be altered. Despite these uncertainties, it is highly likely that greenhouse-forced warming could have significant impacts on water resources, unmanaged ecosystems, agriculture, forestry, and fisheries, and on the societies and economies dependent upon them. Although the impacts likely would be beneficial in some regions, there is a serious risk that the world as a whole might be considerably worse off. Prudence argues that we should mitigate or eliminate the risk of climate change, if we can.

However, atmospheric science also makes it clear that some amount of greenhouse warming is probable in the next century. The warming potential of the greenhouse gases that have already accumulated in the atmosphere has probably not been fully expressed because of the great capacity of the oceans to absorb heat before they warm noticeably. Hence, even if emissions of greenhouse gases were reduced quickly enough to avoid further accumulation of them in the atmosphere, some additional warming would be likely. If even in the best of cases we cannot totally avoid greenhouse warming and consequent climate change, prudence suggests that we look for ways to adapt to whatever the change may be.

Since we probably cannot avoid some amount of greenhouse warming, prudence suggests that we look for ways to adapt to the consequent climate change.

Adaptation and mitigation are sometimes treated as mutually exclusive approaches for dealing with global warming, and arguments in support of one approach may be treated as threats by advocates of the other. In a 1987 article, "Global Climate Change: Toward a Greenhouse Policy," in *Issues in Science and Technology*, Jessica Matthews described "adaptionists" as those who emphasize learning to live with greenhouse warming, and "preventionists" as those who emphasize the need to slow and eventually halt warming. This schismatic classification is, we believe, a misreading of the relationship. Surely few adaptionists,

if any, believe that permanently increasing warming would pose no threat to global society. And surely the most committed preventionist, if convinced that some warming is inevitable, would deem it incumbent upon government to undertake adaptive action to reduce the consequent threats to life and property.

That the adaptation/mitigation argument has progressed from the either/or stage is evidenced in a number of ways. Scientists attending the second World Climate Conference held in Geneva, Switzerland, in November 1990 recognized the need for research to strengthen our understanding of the potential impacts of climate change and of ways to adapt to it. Another manifestation is the creation within the executive branch of the U.S. government of the committee on Mitigation and Adaptation Research Strategies (MARS) to coordinate interagency activities on those strategies.

Finding the right mix

Adaptation and mitigation policies are simultaneously complements and substitutes. The policies are complements in the sense that they can be, and should be, pursued jointly. They are also substitutes, meaning that there are tradeoffs between them as policies for dealing with global warming. Many, if not most, of the resources that could be devoted to the development of adaptive responses to climate change could also be devoted to pursuit of mitigation. The more resources that are devoted to one course, the fewer available for the other.

As an economic issue, the critical question is: What are the costs and benefits of alternative levels of effort devoted to the two courses of action? The benefits are the social values of damages averted; costs are the social values of the resources devoted to the aversion effort that could have been turned to some other purpose. Many of the costs and benefits could be expressed in dollars—for example, the value of the labor and capital used to build barriers against a rise in sea level. Other costs and benefits, however, could not be adequately expressed in dollars—for example, the loss of ecological values in unmanaged forests or the community values preserved where successful adaptation permits continued farming in a region disadvantaged by climate change. The nonquantifiable costs and benefits likely would be of major importance. Despite the uncertainty about them, they must be taken into account in thinking about the relative merits of adaptive and mitigative responses to climate change.

Whatever the answers to the economic question, the critical policy issue is to find the mix of adaptation and mitigation measures that maximizes the net social benefits of efforts to deal with climate change. This policy mix defines the total amount of resources that should be devoted to dealing with climate change, and also the socially optimum allocation of resources between adaptation and mitigation.

The outcome of this assessment of the relative merits of adaptation and mitigation strategies would not be as tidy as the foregoing statement might suggest. The great uncertainty about the costs and benefits of the two approaches, and the political struggle among the various interests with a stake in the outcome, assure that choices about the mix of strategies would be anything but clearcut. The point here is that however fuzzy the decision-making

Photo courtesy of Dr. Kenneth Hubbard, University of Nebraska-Lincoln

Technical advances like this automatic weather station, which guides irrigation scheduling, could help save water when supplies are short, as they may be if the climate changes.

process, the choices should reflect recognition that because there are tradeoffs between adaptation and mitigation, the concept of an optimum mix of the two approaches is meaningful.

Two kinds of adaptive response

It is also important to recognize that there are two kinds of adaptive response to climate change, to which we now turn. One response includes all those things people would be induced to do within the existing institutional and policy regime. The other consists of institutional and policy changes that would be called for where and when the existing regime proved inadequate to deal with the impacts of climate change. The distinction is important because the resources available to undertake changes in institutions and in policies are always limited. These resources can be conserved to the extent that adaptations undertaken within the existing institutional and policy regime are successful.

Examples of the two kinds of adaptive response to climate change can be found in agriculture. Studies of the impacts of climate change on agriculture show that in many areas, including the U.S. Midwest, crop yields (output per acre) might fall with higher temperatures and less precipitation. The fall in yields would increase production costs to farmers, inducing them to investigate existing technologies and management practices for better ways to adapt to the changed climate. Farmers might turn to conservation tillage, a technique that conserves more soil moisture than the more commonly used tillage techniques. They might also adopt already available crop varieties that are better adapted to the hotter and drier climate, and invest in irrigation to counter the decline in precipitation. All of these adaptations are examples of measures that people would be induced to undertake within the existing institutional and policy regime.

However, in some circumstances these induced adaptations may be judged inadequate in the sense that after they have been made, society appraises the remaining costs of climate change as unacceptably high. In such a case, institutional or policy changes would be called for to develop additional adaptations that would bring the remaining costs within acceptable limits.

If farmers find that the alternatives available to them from among existing technologies and management practices are inadequate to compensate for the negative impacts of climate change, they may face the prospect of going out of farming, and perhaps leaving a region altogether. This prospect could stimulate agricultural research institutions and those charged with responsibility for agricultural policy to invest more in research to develop a new set of technologies and practices better adapted to the changed climatic regime. Institutional rules for allocating irrigation water might also be changed to give farmers greater flexibility in using water on their own farms and in transferring it among farms.

Researchers at Resources for the Future projected climate conditions of the dust bowl years on Missouri, Iowa, Nebraska, and Kansas to study the potential impacts of and response to climate change in those states.

Prospects for adaptation

The power of adaptation to offset negative consequences of climate change, or to permit exploitation of favorable consequences, has been little studied. It is likely that adaptive responses would be powerful in some circumstances and weak in others. A study conducted by Resources for the Future of the impacts of and responses to climate change in the four-state region of Missouri, Iowa, Nebraska, and Kansas showed that adaptations would significantly reduce the negative impacts of a hotter and drier climate on crop yields. RFF researchers projected climate conditions of the 1930s (the dust bowl years), which are consistent with predictions of hotter and drier weather produced by some climate models, on that region as it might be in 2030. Simulation models of plant growth indicated that, in the absence of adaptations, the production of corn, sorghum, and soybeans (three of the principal crops in the region) would be about 22 percent less in 2030 than if the climate did not change. When allowance was made for adaptations that farmers could make, including new technologies developed by research institutions, the simulation models showed a decline in production of corn (the most sensitive to climate change of the crops studied) of only 9 percent.

If adaptive responses within the existing institutional and policy regime prove inadequate, institutional and policy changes would be needed.

These results are, of course, speculative, but they are consistent with the history of the adaptability of farmers and of

the ability of agricultural research institutions to respond to changing conditions of resource scarcity with which farmers must deal. The results are suggestive, therefore, of the power of adaptation in responding to climate change and of the importance of distinguishing between the two kinds of adaptive response.

In order to fully capture the benefits of the adaptive strategy to climate change, much more knowledge about the payoffs of various kinds of adaptation will be needed. The same could be said, of course, about mitigation strategies. But in at least one way adaptation is more complicated than mitigation. The physics of the greenhouse effect is understood, as are the ways to diminish the threat of global warming. Adaptation, however, raises a different set of problems stemming from the fact that we do not know how climate will change in any particular region and, hence, cannot know what the impacts of climate change will be. Regional climate changes are unpredictable as yet, and the prospects for improved predictability in the near term are poor. Thus the investment of great effort and resources now in developing specific adaptations to climate change for specific industries or infrastructures in specific regions would probably not pay off well.

One exception is adaptation to a rise in sea level, which will affect all of the world's shores, although not uniformly. As the atmosphere and (eventually) the seas warm, sea level will rise, threatening coastal areas around the world. But here, too, the possible rise in sea level is difficult to predict; estimates range from less than 0.5 meters to more than 1.5 meters during the course of the next century. In fact, it seems likely that the greatest impacts on land and people adjacent to the sea could be more the result of changes in wind force and direction than of a rise in sea level per se.

Finding a sensible adaptation strategy

What, then, is a sensible strategy for adapting to future changes in climate? First, we must gain a better understanding of the sensitivity and vulnerability of specific regions, industries, ecosystems, and societies to the normal range of climatic variability, and what can be done to diminish this sensitivity and vulnerability. For example, the North American Great Plains and many other regions of the world are subject to recurrent droughts. What technical and institutional measures can be applied to diminish the impacts of drought so that these regions can be made more resilient than they are today? Knowledge gained from answering this question would be directly applicable in the event that droughts in these regions become more severe or more frequent.

Better understanding how to reduce the vulnerability of specific regions to the normal range of climatic variability is the first step in a sensible adaptation strategy.

Second, research establishments should be working now to develop better responses to climate variability. Such research would produce many of the techniques needed for adaptation to climatic change because the primary threat of that change lies in more severe and more frequent extreme events.

Third, as knowledge of the dynamics of climatic change improves or as signs of change are perceived, or both, scientific and engineering resources should be assigned to the development of the specific adaptations needed. This would require, of course, that the scientific establishment remain capable of effective reaction from now until the time at which adaptations must be put into action.

The adaptive strategy might have a high payoff, and research to identify opportunities for adaptation and to provide knowledge and techniques needed to adapt would be a central part of that strategy. The developed countries seem well positioned to follow this strategy because their reliance on markets promotes flexibility in reallocating resources and their research establishments are strong. But what of the developing countries, with their smaller endowments of means and resources? Will they have the capacity to adapt as easily as the countries with higher per capita income?

There is no reason to believe that the developing countries, as a group, will be exposed to worse climatic changes than will the developed countries. It is certain, however, that their margin of survival would be smaller and that their opportunities for adapting to climatic change might be severely limited where the institutional and technical infrastructure, including research capacity, is weaker. In a paper entitled "Potential Strategies for Adapting to Greenhouse Warming: Perspectives from the Developing World" in the RFF volume *Greenhouse Warming: Abatement and Adaptation* (1989), N. S. Jodha, an agricultural economist from India, argues that farmers in developing countries use age-old techniques to cope in times of stress, and that these provide an arsenal from which to draw when climate change imposes a need for adaptation. Jodha provides many examples of the use of these techniques in India. There are exceptions, of course. In areas where agriculture is already risky because of severe climate or poor soils, particularly in the semiarid tropics, any detrimental climate change, however small or slow, can accentuate the risks and have serious impacts.

Because the developing countries are preoccupied with raising their currently low standards of living, they have shown relatively little interest in mitigating global warming. As Jodha shows, however, these countries, without necessarily having any greater interest in an adaptive strategy, nonetheless have accumulated substantial experience in adaptation, particularly in agriculture. Of course, the developing countries, like the developed countries, will need more knowledge of the prospective impacts of climate change and of possibilities for effective adaptive responses. There is a mutuality of interest here between developed and developing countries that may foster cooperative efforts in devising strategies for adaptation, even if agreement on strategies for mitigation remains elusive. ■

Pierre R. Crosson and Norman J. Rosenberg are senior fellows in the Energy and Natural Resources Division at RFF. Rosenberg is director of RFF's Climate Resources Program.

Applicants sought for leadership program

The National Center for Food and Agricultural Policy at Resources for the Future is now accepting fellowship applications for the seventh annual (1992) Leadership Development Program. Applicants must have at least a baccalaureate degree and have completed at least five years' work in a field related to food and agriculture.

The program provides an opportunity for mid-career professionals to obtain four-week public policy fellowships in Washington, D.C. Those selected participate in specially designed seminars and workshops. Areas of study include the policymaking process and policies relating agriculture to food and nutrition, rural development, international trade, and natural resources and the environment. Those selected also undertake independent policy projects dealing with a food or agricultural policy issue of their choice.

The 1992 program will be divided into two two-week segments, separated by a two-week interval. It will run from January 28 to February 12 and March 1 to March 14, 1992. Tuition is $2,400. Limited support is available from the National Center for fellows in special circumstances.

To obtain an application form for the program, write to: 1992 Leadership Development Program, National Center for Food and Agricultural Policy, Resources for the Future, 1616 P Street, N.W., Washington, D.C. 20036. Telephone (202) 328-5011. The deadline for submitting applications is September 13, 1991. ■

Global warming documentary being aired on public television

"Future Conditional: Global Warming," a documentary produced in a joint venture with Resources for the Future by Screenscope, Inc., will be aired on most public broadcasting stations this spring. The program, which focuses on the causes of global warming, its policy aspects, and strategies for dealing with it, is already available to the public on VHS cassette.

RFF's involvement in the documentary stems from its interest in filling a major gap in the public's understanding of the complex problem of global warming. According to a Princeton University study cited in the program, although the majority of the public has heard of the greenhouse effect, it often confuses that phenomenon with others such as the hole in the stratospheric ozone layer over the Antarctic. Moreover, the public has no clear notion of the consequences of a rise of even a few degrees in temperature.

Norman Rosenberg, director of RFF's climate resources program and scientific adviser for the documentary, asserts that just as important as making the public aware of the potential for global warming is the presentation of an impartial and balanced account of the problem. "Most documentaries do not give a clear statement of what we do and do not know about greenhouse warming and climate change. Often presentations are sensational, taking a somewhat catastrophic view of global warming. 'Future Conditional' tries to examine the subject objectively and comprehensively."

Since some amount of greenhouse warming is probable in the next century, one of the most important points conveyed in the documentary, says Rosenberg, is the need to adapt to climate change. "In this program we explain that adaptation and mitigation are not mutually exclusive alternatives for dealing with climate change, but complementary ones." As the documentary makes clear through examples of agricultural and engineering advances, technology can offer some protection against and ways of adjusting to climate change. Rosenberg notes that global warming may benefit people in some parts of the world but that even adapting to positive change takes time and resources.

A significant feature of the program, in Rosenberg's view, is its examination of global warming as a problem with important economic, social, and political implications. Developing countries worry that controlling the emission of greenhouse gases may come at the expense of their economic growth. In addition to implementing energy efficiency and conservation on their own, the developed countries may need, at some cost to themselves, to help developing countries reduce their dependence on fossil fuels. As Rosenberg observes, "there must be an understanding that some tradeoffs are inescapable if we are to take steps to deal with global warming."

For information about how to purchase a VHS cassette of "Future Conditional: Global Warming," see page 16. ■

To order books, add $3.00 for postage and handling per order to the price of books and send a check made out to Resources for the Future to:

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New books

Economics and Episodic Disease: The Benefits of Preventing a Giardiasis Outbreak, by Winston Harrington, Alan J. Krupnick, and Walter O. Spofford, Jr.

Efforts to design policies for improving the safety of drinking water have been hampered by poor information on the health and related benefits of more advanced water treatment. Through surveys of individuals, businesses, and government officials, the authors have estimated the costs associated with a large outbreak of the waterborne diarrheal disease giardiasis in northeastern Pennsylvania in 1983. These costs include medical expenses and the time and expense of activities taken to avoid drinking the water. Building a water treatment plant capable of removing this protozoan is found to be justified if more than four outbreaks could be expected over the twenty- to thirty-year lifetime of the plant.

June 1991. Approx. 240 pp.
$20.00 cloth. 0-915707-59-4

Technology Options for Electricity Generation: Economic and Environmental Factors, by Hadi Dowlatabadi and Michael A. Toman

Investments in electricity generation technologies have been influenced by increased competition, tightened environmental controls, technical innovations, and other factors over the past two decades. Dowlatabadi and Toman examine the interplay between economic forces and technological evolution in the electricity generation industry. They evaluate technology and investment choices that minimize economic costs under different market and regulatory conditions. They find that advanced generation technologies utilized in plants of a smaller size than conventional coal plants are likely to be the most cost-effective source of new electrical generating capacity under a wide range of potential circumstances. Their study also illustrates the potential of expanded interregional power trade to reduce electricity generation costs.

May 1991. 87 pp.
$12.95 paper. 0-915707-58-6

Environmental, business, and government interests represented at RFF Council meeting

At the first annual meeting of the RFF Council, representatives from environmental organizations, federal agencies, and industry exchanged views on the emergence of state and local governments as potent forces in environmental regulation. Among the guest speakers at the April 4 meeting in Colorado Springs, Colorado, were James Scherer, Region 8 administrator of the U.S. Environmental Protection Agency; David Roe of the Environmental Defense Fund; and Ray Sheppach, executive director of the National Governors Association.

Roe, a principal author of Proposition 65 (California's successful 1986 ballot initiative to limit discharges of toxic substances), noted that regulation of hazardous pollutants by the federal govern-

(continued next page)

Discussion papers

RFF discussion papers convey the early results of research for the purpose of comment and evaluation. They are available at modest cost to interested members of the research and policy communities. Price includes postage and handling. Prepayment is required. To order discussion papers, please send a written request, accompanied by a check, to the Publications Office, Resources for the Future, 1616 P Street N.W., Washington, D.C. 20036-1400.

The following papers have recently been released.

Center for Risk Management

- "The Determinants of Pesticide Regulation: A Statistical Analysis of EPA Decision-making," by Maureen L. Cropper, William N. Evans, Stephen J. Berardi, Maria M. Ducla-Soares, and Paul R. Portney. (CRM91-01) Free

- "Policies for the Regulation of Global Carbon Emissions," by Wallace E. Oates and Paul R. Portney. (CRM91-02) Free

Energy and Natural Resources Division

- "How the CO_2 Issue Is Viewed in Different Countries," by Peter M. Morrisette and Andrew J. Plantinga. (ENR91-03) $5.00

- "Utility Investment Behavior and the Emission Trading Market," by Douglas R. Bohi and Dallas Burtraw. (ENR91-04) $5.00

- "Economics and 'Sustainability': Balancing Tradeoffs and Imperatives," by Michael A. Toman and Pierre R. Crosson. (ENR91-05) $5.00

- "The Economic Cost of CO_2 Mitigation: A Review of Estimates for Selected World Regions," by Joel Darmstadter and Andrew J. Plantinga. (ENR91-06) $5.00

- "Equity and International Agreements for CO_2 Containment," by Dallas Burtraw and Michael A. Toman. (ENR91-07) $5.00

- "The NASA Budget: For Whom, For What, and How Big?" by Molly K. Macauley. (ENR91-08) $5.00

Quality of the Environment Division

- "Detecting Heterogeneity and Overdispersion in Poisson Regression Models via Goodness-of-Fit," by John Mullahy. (QE91-06) $2.25

- "Improving System Planning in the Columbia River Basin: Scope, Information Needs, and Methods of Analysis," by Danny C. Lee and Charles M. Paulsen. (QE91-07) $2.25

- "Transportation and Air Pollution in Urban Areas of Developed and Developing Countries," by Alan J. Krupnick. (QE91-08) $2.25

ment has been proceeding at a slow pace. He suggested that states might establish such regulation more quickly and effectively by making businesses bear the burden of proof that their activities and products are safe. Such an approach would give regulated parties incentives to establish safe concentrations of hazardous substances and to perform safety tests.

Continued activism on the part of states in the area of environmental regulation is not assured, however. According to Sheppach, many states that initiated new environmental programs during the 1980s may be less inclined to do so in the 1990s. One reason is the overall change in their economic position. States that formerly operated in the black are now facing budget deficits. Pressures to deal with other social issues may make these states wary of establishing regulatory programs that would require state funds to operate. Sheppach said pollution taxes and other economic incentives may be used more often in the future to help pay for environmental monitoring and enforcement programs.

During the meeting, RFF directors Darius Gaskins and Tom Klutznick noted that leaders in government, business, and environmental organizations form a critical link between the scholarly research conducted by Resources for the Future and the needs of policymakers. The RFF Council was recently established to recognize those leaders who combine an active interest in natural resource and environmental policy issues with a concern for RFF's financial well-being. Interactions with government officials, environmental advocates, and council members will assist RFF in shaping its research agendas and communicating its research results. ■

Photo courtesy of Bob McIntyre

The first annual meeting of the RFF Council brought together environmental, business, and government interests. Pictured are David Roe of the Environmental Defense Fund; Mason Willrich, president and chief executive officer of PG&E Enterprises; Robert Fri, president of Resources for the Future; and Darius Gaskins, visiting professor at the Kennedy School of Government (Harvard University). Willrich and Gaskins are members of RFF's board of directors.

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