Global Warming: Slowing the Greenhouse Express

POLICYMAKERS WHO yearn for the familiar will undoubtedly have the opportunity to struggle with perennial problems such as recessions, inflation, and government deficits. As if traditional ills are not enough, in the late 1980s governments were confronted with yet another issue: the deterioration of the global environment. Recent studies have identified four major global environmental concerns: widespread damage from acid rain; the appearance of the Antarctic "ozone hole," interpreted by some as the harbinger of global ozone depletion that threatens to remove the shield from harmful ultraviolet radiation; deforestation, especially in the tropical rain forests, which may upset the global ecological balance and deplete genetic resources; and the "greenhouse effect," which threatens global warming and major climatic changes in the decades to come.

Although all four issues concern policymakers, this chapter concentrates on global warming, both because it is likely to have the most important economic impact and because it has been the source of the greatest controversy. The discussion covers the scientific theory and evidence of global warming; the economic effects of climatic change; the kinds of policy responses that might be available; and policy recommendations for the near term.

Scientific Theory and Evidence of Global Warming

For almost two centuries scientists have suspected that climate could be affected by changes in the chemical composition of the earth's atmosphere. The first analysis of this idea was carried out in 1896 by S. A. Arrhenius, who estimated that a doubling of the atmospheric con-
TABLE 6-1. Estimated Atmospheric Concentrations of Important Greenhouse Gases, Selected Years, 1850–2100

<table>
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</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>290,000</td>
<td>348,000</td>
<td>630,000</td>
<td>0.16</td>
<td>0.52</td>
</tr>
<tr>
<td>Methane</td>
<td>880,000</td>
<td>1,675,000</td>
<td>3,100,000</td>
<td>0.56</td>
<td>0.54</td>
</tr>
<tr>
<td>Nitrogen oxides</td>
<td>285,000</td>
<td>340,000</td>
<td>380,000</td>
<td>0.15</td>
<td>0.10</td>
</tr>
<tr>
<td>Chlorofluorocarbonsb</td>
<td>0</td>
<td>0.62</td>
<td>2.90</td>
<td>...</td>
<td>1.37</td>
</tr>
</tbody>
</table>


1. Projected from EPA, Policy Options.
2. Includes only major sources, CFC-11 and CFC-12.

The concentration of carbon dioxide (CO₂) would increase global mean temperature by 4° to 6° centigrade (°C). What causes the greenhouse effect? The atmosphere is composed of a number of "radiatively active" gases that absorb radiation at different points of the spectrum. Those known as the "greenhouse gases" (GHGs) are transparent to incoming solar radiation but absorb significant amounts of outgoing radiation. The net result is an increase in the earth's temperature of about 33°C (59°F). The greenhouse effect helps explain the hot temperatures on Venus along with the frigid conditions of Mars.

Human activities are raising atmospheric concentrations of greenhouse gases significantly and thus pose a threat to the climate. GHGs of greatest concern are carbon dioxide, methane, nitrogen oxides, and chlorofluorocarbons (CFCs). Scientific monitoring has firmly established that these GHG concentrations are increasing (see table 6-1).

Not all greenhouse gases are created equal. GHGs have different radiative properties and different lifetimes. Table 6-2 shows the important greenhouse gases, their "instantaneous" and "total" contribution to global warming, and the industries in which the emissions originate.


2. Traditionally, the relative effect of greenhouse gases is measured by their instantaneous contribution to global warming (in °C). The problem with this method is that GHGs differ in their lifetimes and chemical transformations. In order to calculate the total contribution of each GHG, I have estimated the sum of the instantaneous contributions over the indefinite future (in °C-years).
### Table 6.2. Estimated Contribution of Different Greenhouse Gases to Global Warming for Concentration Changes, 1985–2100

<table>
<thead>
<tr>
<th>Greenhouse gas</th>
<th>Relative contribution (percent)</th>
<th>Source of emission</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Instantaneous*</td>
<td>Total*</td>
</tr>
<tr>
<td>Sources by chemical compound</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>76.1</td>
<td>94.7</td>
</tr>
<tr>
<td>Methane</td>
<td>9.6</td>
<td>0.8</td>
</tr>
<tr>
<td>CFCs</td>
<td>11.6</td>
<td>3.3</td>
</tr>
<tr>
<td>Nitrous oxides</td>
<td>2.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Sources by economic activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>62.8</td>
<td>76.2</td>
</tr>
<tr>
<td>Agriculture</td>
<td>20.6</td>
<td>19.8</td>
</tr>
<tr>
<td>Industry</td>
<td>0.7</td>
<td>0.1</td>
</tr>
<tr>
<td>Natural</td>
<td>4.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Other</td>
<td>11.6</td>
<td>3.3</td>
</tr>
</tbody>
</table>

**Sources**: For chemical compounds, see William D. Nordhaus, "Contribution of Different Greenhouse Gases to Global Warming: A New Technique for Measuring Impact," Yale University, Department of Economics, February 1990, for economic activity, see 3. William D. Nordhaus, "To Slow or Not to Slow: The Economics of the Greenhouse Effect," paper prepared for the 1990 annual meeting of the American Association for the Advancement of Science. Estimates of emission sources are from EPA, Policy Options vol 1, chap. 2

a: The relative contribution to global warming over undeterminate future
b: Sources highly uncertain for methane and nitrous oxides

CO₂ is the principal contributor to global warming, and most of it comes from the combustion of fossil fuels. Of the fossil fuels, natural gas emits 58 percent as much CO₂ per unit of energy as coal, and petroleum 81 percent as much. Next in importance are the chlorofluorocarbons (CFCs), which are small in volume but have a warming potential almost 20,000 times as powerful as CO₂ per unit of volume.

One difficulty in estimating the economic and environmental damage from climatic change and the costs of slowing it is to find an index that can apply to both. In this discussion, I use the “CO₂ equivalent” of GHG emissions, which can provide a unit of measurement for the cost effectiveness of policies in different sectors.

**Climate Models and Forecasted Climatic Change**

No one disputes the buildup of greenhouse gases. The question is, how can one predict the climatic changes this buildup will cause many
years into the future? Today, mathematical models are used to trace the
effect of changes in the radiative balance on climatic variables such as
temperature, humidity, winds, soil moisture, and sea ice. Because these
changes are unprecedented in recorded history, the models cannot rely
on historical experience, but must extrapolate beyond current observa-
tions.

Large general-circulation models (GCMs) simulate changes in the
weather over a century or more. The largest models take average
conditions in 500-kilometer-square grids through several layers of the
atmosphere. Such models are extremely expensive to run, and a single
CO₂ scenario might take a supercomputer up to a calendar year to
calculate.

Interestingly, the basic estimates of the effect of a CO₂-equivalent
doubling on equilibrium appear to have changed little since the earliest
calculations. A National Academy of Sciences panel concluded in 1983:
"When it is assumed that the CO₂ content of the atmosphere is doubled
and statistical thermal equilibrium is achieved, all models predict a global
surface warming. . . . [GCMs] indicate global warming [from CO₂
doubling] to be in the range between about 1.5 and 4.5 °C." Even with
improvements in models and faster computers, there has been no
significant narrowing of this estimate since 1983. The current range of
scientific opinion is shown in table 6-3. Most experts believe that mean
temperature will rise and that precipitation and runoff will increase as
a result of the warmer climate. Some models predict hotter and drier
climates in midcontinental regions, such as the U.S. Midwest. Few
modelers expect to be able to forecast regional climatic changes over
smaller areas, and not many modelers expect to do so with any degree
of accuracy in the foreseeable future.

Temperature Records

There are several possible ways to test the climate models, but they
can only be fully validated when and if global temperatures actually
begin to rise. According to available historical records, which have very
inadequate coverage for much of the globe, global mean temperature

3. Carbon Dioxide Assessment Committee, "Synthesis," in NRC, Changing Climate,
p. 28.
has increased about 0.5° C since the 1880s. Whether the increases observed in the temperature record are consistent with the predictions of climate models is a hotly debated question. Some authors have used statistical techniques to test for the presence of a “greenhouse signal” in the upward trend over the past century. The statistical hypothesis that the global mean temperature follows a trendless process can be rejected at a high level of confidence.

Still, a great deal of evidence suggests that climatic variables fluctuate over periods of a century or more. Unfortunately, there is not enough known about the background trends and cycles to determine whether the warming in recent years is a normal fluctuation or something new and different. Although statistical analysis of the historical record has lagged far behind the construction of new and more refined GCMs, this record is an important, independent source of evidence about the pace of global warming.

4. The eminent climatologist James Hansen has stated that he is “99 percent” confident that the warming of the 1980s was associated with the greenhouse effect. See James Hansen, testimony before the Senate Energy Committee, June 23, 1988. According to other respected scientists, however, “No conclusion about the magnitude of the greenhouse effect in the next century can be drawn from the 0.5° C warming that has occurred in the last 100 years." See George C. Marshall Institute, *Scientific Perspectives on the Greenhouse Problem* (Washington, 1989), p. 29.
Uncertainties about Future Climatic Change

A particularly nettlesome aspect of this subject is the chain of uncertainties about the magnitude, timing, and effects of climatic change. Uncertainties include the rate of economic growth over the next century and the rate of emission of GHGs per unit of economic activity, not to mention the rate of atmospheric retention of different GHGs, the equilibrium relationship between increased concentrations in GHGs and climate change, the speed with which actual climate will move to the new equilibrium, and the extent to which climate would change were humans influences absent.

A rational response to climatic change must take these uncertainties into account. I have combined estimates of uncertainty about future climate change from a number of sources. The assumed effect of rising GHGs follows the consensus of modelers that a doubling of CO₂ would in equilibrium raise global temperatures by 3°C (with a standard deviation of 1°C). I have derived an estimate of the lag of actual temperature behind the equilibrium temperature using evidence from GCMs and the historical record.

Figure 6-1 presents my estimated range of greenhouse warming over the period from 1850 to 2000 and an index of actual mean surface temperature over the past century. The median estimate of realized warming from 1800 to 1990 is about 0.7°C, and about 0.6°C from the beginning of the temperature record in 1880. This estimate approximates reasonably well the actual temperature increase of 0.5°C shown by the highly volatile series in figure 6-1.

Figure 6-2 shows the estimated range of greenhouse warming over the next century. My projection of the most likely global temperature rise is 1.8°C from 1800 to 2050 and 3.3°C from 1800 to 2100. According to this calculation, the chances are one in four that the

5. Estimates of the distribution of emissions of some GHGs are derived from William D. Nordhaus and Gary W. Yohe, "Future Carbon Dioxide Emissions from Fossil Fuels," in NRC, Changing Climate, pp. 87–153. Estimates of emissions and concentrations of CFCs, methane, and other GHGs are from Environmental Protection Agency, Policy Options for Stabilizing Global Climate (February 1989), vol. 1: chaps. 1–6.

**FIGURE 6-1.** Actual Global Mean Surface Temperature and Estimated Distribution of Greenhouse Warming, 1850–2000\(^a\)

Degrees centigrade (1880-90 = 0)

![Graph showing actual temperature and percentile distributions over time from 1850 to 2000.]

**FIGURE 6-2.** Calculated Change in Temperature, 1800–2100\(^a\)

Degrees centigrade (1800 = 0)

![Graph showing calculated temperature change from 1800 to 2100.]

\(^a\) Percentiles represent distribution of estimated future greenhouse warming. The range spanned by 25th and 75th percentiles represents a range of temperature increases in which warming has a one-in-two chance of lying.
temperature change from 1800 to 2050 will be less than 1.5° C or greater than 2.2° C.

Another important question to ask is when the canonical 3° warming, used in many economic studies, will occur. I estimate that the average temperature will rise 3° from 1800 by 2090; there is a one-in-four chance that this much warming could occur by 2075, but a less than a one-in-twenty chance that it will occur before 2050. On the optimistic side, these calculations suggest that there is almost one chance in two that global mean temperature will rise less than 3° C between 1800 and 2100.

It should be emphasized that projecting climatic change is hazardous at best. But these estimates suggest that a 3° C warming is most likely to occur about a century from now and is quite unlikely to occur before the middle of the next century.

Social and Economic Effects of Climatic Change

Technological change has made it possible for human societies to thrive in a wide variety of climatic zones, with the result that variables such as temperature or humidity have little effect on economic activity in advanced countries. Indeed, since the development of air conditioning, migration patterns in the United States have favored warmer regions.

At the same time, globally averaged surface temperature is not the most important variable to consider when estimating effects. Precipitation or water levels and extremes like droughts or freezes are likely to be more significant. Mean temperature is chosen because it is a useful index of climatic change that tends to be associated with most other important changes. Another point to note is that the degree of projected climatic change is quite small in comparison with the changes normally experienced from day to day. The change in temperature normally experienced between 8:00 and 9:00 A.M. on an April morning is likely to be far greater than the expected change from 1990 to 2090. Few people are likely to notice the CO₂ signal amidst the pandemonium of their daily lives.

Economic Effects in the United States

Climatic change is likely to have different effects on different sectors of the economy. In general, those sectors that interact with unmanaged

7. I concentrate on the United States because the most careful studies of the impact
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ecosystems—in other words, that are heavily dependent on naturally occurring rainfall, runoff, or temperatures—may be hit the hardest. Agriculture, forestry, and coastal activities fall into this category. Most parts of the U.S. economy have little direct interaction with climate, and the effects of climatic change are likely to be very small in these sectors. For example, climatic change is not likely to pose a direct threat to activities performed in a carefully controlled environment, such as cardiovascular surgery or the manufacture of microprocessors.

Table 6-4 presents a breakdown of U.S. national income, organized by the sensitivity of the sector to greenhouse warming. Approximately 3 percent of U.S. national output originates in climate-sensitive sectors and another 10 percent in sectors modestly sensitive to climatic change. About 87 percent of national output comes from sectors that are negligibly affected by climatic change. These measures of output may understatement the impact of climatic change on well-being because they omit important nonmarket activities—especially leisure activities—that may be more sensitive to climatic change than measured output.

Information from recent studies can be used to speculate on the likely economic effects of climatic change. Of the sectors for which numerical estimates are available, agriculture is the most climate-sensitive. Some studies suggest that greenhouse warming will reduce the yields of many crops, but the higher CO2 concentrations will have a fertilization effect and will tend to raise yields. A National Academy of Sciences panel concluded that "we do not regard the hypothesized CO2-induced climate changes as a major direct threat to American agriculture over the next few decades." The Environmental Protection Agency (EPA) has estimated that a CO2 doubling may lead to a rise or fall in the value of U.S. agricultural output by as much as $10 billion annually, depending on the magnitude of the climate change. The forest products industry may also benefit from CO2 fertilization. Water systems (such as runoff in

8. “National income” is total national output measured at factor costs. It equals GNP less indirect business taxes and depreciation.
10 EPA, Potential Effects of Global Climate Change on the United States, p. 45.
11 Clark S. Binkley, “A Case Study of the Effects of CO2-Induced Climatic Warming on Forest Growth and the Forest Sector. B. Economic Effects on the World’s Forest

<table>
<thead>
<tr>
<th>Sector</th>
<th>Value (billions of dollars)</th>
<th>Percentage of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total national income</td>
<td>2,414.1</td>
<td>100.0</td>
</tr>
<tr>
<td>Potentially severe effect</td>
<td>74.8</td>
<td>3.1</td>
</tr>
<tr>
<td>Farms</td>
<td>67.1</td>
<td>2.8</td>
</tr>
<tr>
<td>Forestry, fisheries, other</td>
<td>7.7</td>
<td>0.3</td>
</tr>
<tr>
<td>Moderate potential effect</td>
<td>243.6</td>
<td>10.1</td>
</tr>
<tr>
<td>Construction</td>
<td>109.1</td>
<td>4.5</td>
</tr>
<tr>
<td>Water transportation</td>
<td>6.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Energy and utilities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy (electric, gas, oil)</td>
<td>45.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Water and sanitary</td>
<td>5.7</td>
<td>0.2</td>
</tr>
<tr>
<td>Real estate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land-rent component</td>
<td>51.2</td>
<td>2.1</td>
</tr>
<tr>
<td>Hotels, lodging, recreation</td>
<td>25.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Negligible effect</td>
<td>2,095.7</td>
<td>86.8</td>
</tr>
<tr>
<td>Mining</td>
<td>45.1</td>
<td>1.9</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>581.3</td>
<td>24.1</td>
</tr>
<tr>
<td>Other transportation and communication</td>
<td>132.6</td>
<td>5.5</td>
</tr>
<tr>
<td>Finance, insurance, and balance real estate</td>
<td>274.8</td>
<td>11.4</td>
</tr>
<tr>
<td>Trade</td>
<td>349.4</td>
<td>14.5</td>
</tr>
<tr>
<td>Other services</td>
<td>325.2</td>
<td>13.5</td>
</tr>
<tr>
<td>Government services</td>
<td>337.0</td>
<td>14.0</td>
</tr>
<tr>
<td>Rest of world</td>
<td>30.3</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Source: Based on U.S. National Accounts, Survey of Current Business, July 1984, pp. 70-71

a National income in electric, gas, sanitary industry is subdivided on the basis of consumption of major components.
b Estimate of land-rent component is drawn from two sources: national balance sheets data on values of land and structures and surveys of housing prices. Estimate assumes that 25 percent of nonlabor income in real estate industry is from land rents.

rivers or the length of ice-free periods in lakes and rivers) may be affected, but the costs are likely to be determined more by the rate of climatic change than by the new equilibrium climate. Construction in temperate climates will be favorably affected because of a longer period of warm weather.

The effect on recreation and water transportation will be mixed,
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depending on the initial climate. Cold regions may gain while hot regions may lose; investments in water skiing will appreciate, whereas those in snow skiing will depreciate. But for the much of the economy—manufacturing, mining, utilities, finance, trade, and most service industries—it is difficult to estimate the direct effects of the projected climatic changes over the next fifty to seventy-five years.

Most studies indicate a gradual rise in average sea level over the next century. The consensus until recently was that sea level might rise 70 centimeters in the next century, but recent evidence has cut this estimate sharply. Using the estimate of 70 centimeters, the EPA projects the costs of sea-level rise to be about 6,000 square miles in land lost; a total capital outlay on the order of $100 billion for the protection of high-value property (by levees and dikes); and costs of protecting open coasts.\textsuperscript{12} Total costs are approximately 0.1 percent of cumulative gross private domestic investment over the period 1985–2050.

Greenhouse warming will also increase the demand for space cooling and decrease the demand for space heating. The net impact of CO\textsubscript{2} doubling on energy use is estimated to be less than $1 billion at 1981 levels of national income.

The fact that many valuable goods and services are not captured in the net of the national income accounts might affect the calculations. The most notable ones are human health, biological diversity, amenity values of everyday life and leisure, and environmental quality. Some people will place a high moral, aesthetic, or environmental value on preventing climate change, but I know of no comprehensive estimates of what people are willing to pay to stop greenhouse warming.\textsuperscript{13} I am aware of no studies that point to major nonmarket costs, but further analysis will be required to determine whether these omitted sectors will affect the overall assessment of the cost of greenhouse warming.

In sum, the climatic changes induced by a doubling of CO\textsubscript{2} concentrations are likely to have only a small effect on the U.S. economy. The best guess today is that the impact, in terms of those variables that have been quantified, is likely to be around one-fourth of 1 percent of national income. However, current studies omit a number of potentially important effects, so this estimate has a large margin of error.


\textsuperscript{13} EPA, \textit{Potential Effects of Global Climate Change on the United States}. 
Economic Effects outside the United States

Only a few preliminary studies have been completed for other countries, so no general conclusions can be drawn at this time. Existing evidence suggests that other advanced industrial countries are likely to experience modest effects, similar to those in the United States. Detailed studies for the Netherlands and a less comprehensive study for six large regions (the United States, Europe, Brazil, China, Australia, and the Soviet Union) found that the overall impact of a CO₂-equivalent doubling will be small and probably difficult to detect over the next half-century or more.¹⁵

Small countries that are heavily dependent on coastal activities or that experience a significant climatic change may be severely affected. It has been suggested that low-lying areas in Bangladesh may be inundated and that the Maldives may eventually disappear, but the timing of these impacts is conjectural. Particular concerns arise where people or activities cannot easily migrate in response to climate change. Such situations include natural reserves (like Yosemite) or populations limited to small areas (like South Sea islanders).

Developing countries are probably more vulnerable to greenhouse warming than are industrialized countries, particularly those poor countries with few resources to divert to problems connected with climatic change. However, most of these countries depend on agriculture, and the benefits of CO₂ fertilization might offset the damages.

In summary, I conclude that CO₂-induced climatic change is likely to produce a combination of gains and losses of uncertain magnitude and distribution with no strong presumption of substantial net economic damages. This conclusion applies especially to large, wealthy, and geographically diverse countries, with many unanswered questions about small, poor countries. This statement should not be interpreted as being a brief in favor of climatic change. Rather, it suggests that those who paint a bleak picture of desert Earth devoid of fruitful economic activity may be exaggerating the injuries and neglecting the benefits of climatic change.

¹⁴. Remember that the studies referred to here represent "best-guess" scenarios of climatic change. They omit uncertainties and possible nonlinearities, which are covered later in the chapter.

Possible Responses to the Threat

A wide variety of responses have been suggested to deal with the threat of global warming (see figure 6-3). The option that has received the greatest public attention is to slow or prevent the warming itself. Most policy discussion of this option has focused on reducing energy consumption, switching to nonfossil fuels, and undertaking reforestation to remove CO₂ from the atmosphere. Whatever the final choice, the policy should be structured to obtain the maximum reduction in harmful climatic change for a given level of expenditure.

Second, greenhouse warming could be offset through climatic engineering, for example, by shooting particulate matter into the stratosphere to cool the earth or changing cultivation patterns in agriculture. Although these proposals have not been fully investigated, many environmentalists are opposed to them because “you shouldn’t fool with Mother Nature.”

Third, an effort could be made to adapt to the warmer climate. As the climate changes and the oceans rise, adaptation can take place gradually on a decentralized basis through the automatic response of people and institutions or through markets. In addition, governments can prevent harmful effects by introducing land-use regulations or investing in research on living in a warmer climate.

Preventive Measures

The most important question policymakers face at present, however, is whether major steps should be taken in the near term to prevent global warming. The answer depends on the costs of reducing GHG emissions relative to the damage that they would cause if they continued unchecked.

The little work that has been done on estimating the costs of slowing greenhouse warming has concentrated on reduction of emissions and atmospheric concentrations of greenhouse gases (the first strategy in figure 6-3). These examples—reducing CFC emissions, reducing CO₂ emissions, and reforestation—are not the only options, but they have been studied most intensively.

In my calculations, I measured the cost of preventive measures in tons of CO₂ equivalent. Measures that cost up to $5 per ton of CO₂ equivalent are considered inexpensive; at this cost, global warming could be stopped dead in its tracks at a total cost of less than $40 billion per year (about 0.2 percent of global income). Costs approaching $10 to $50 per ton CO₂ equivalent are expensive but manageable (costing ½ to 2½ percent
FIGURE 6.3. Alternative Responses to the Threat of Greenhouse Warming

Slow or prevent greenhouse warming: reduce emissions and concentrations of greenhouse gases
- Reduce energy consumption
- Reduce GHG emissions per unit of energy consumption or GNP
  - Shift to no-CO$_2$ or low-CO$_2$
  - Divert CO$_2$ from entering atmosphere
- Shift to substitutes for CFCs
- Remove greenhouse gases from atmosphere
  - Grow and "pickle" trees

Offset climatic effects
- Climatic engineering
  - Put particles into stratosphere
  - Species selection and cultivation patterns

Adapt to warmer climate
- Decentralized/market adaptations
  - Population and capital move to new temperate zones
  - Corn belt migrates toward Canada and Siberia
- Central/governmental policies
  - Build dikes to prevent ocean's invasion
  - Regulate land use
  - Conduct research on drought-tolerant crops

of global income). Measures costing more than $100 per ton of CO$_2$ are extremely expensive.

Reducing CFC emissions. Reducing emissions of chlorofluorocarbons into the atmosphere should probably be the first strategy to consider because they are extremely powerful greenhouse gases. Scientists believe that new chemical substitutes for the two most important CFCs can be found that will significantly reduce greenhouse warming. A rough estimate is that these substitutes can reduce warming at a cost of less than $5 per ton of CO$_2$ equivalent. This approach would bring a significant reduction in warming at a modest cost.

Reducing CO$_2$ emissions. More than 95 percent of CO$_2$ emissions come from the energy sector and deforestation. These emissions can be reduced by increasing energy efficiency, decreasing final energy services, substituting less GHG-intensive fossil fuels for more GHG-intensive fossil fuels, substituting nonfossil fuels for fossil fuels, and developing new techniques of production along with new products and services.

Because energy interacts with the economy in so many ways, complex models of the energy system are required to estimate the costs of reducing CO$_2$ emissions. These models must take into account the behavior of
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both producers and consumers as well as possible future technological changes. A number of studies have employed such models to provide estimates of the long-run costs of reducing CO₂ emissions.¹⁶ The results point to two main conclusions.

First, small reductions incur low costs. Reductions of up to 10 percent of CO₂ emissions from the energy sector can be attained over the long run at an average cost of less than $10 per ton of CO₂ reduced. At the current global level of emissions (about 6.5 billion tons of CO₂ a year), a 10 percent reduction would cost around $6 billion a year.

Second, the cost of reducing CO₂ emissions increases rapidly and becomes extreme when the reductions are substantial. I estimate that in the long run, but with today's energy technologies, the marginal cost of a 50 percent reduction in CO₂ emissions is approximately $130 per ton of CO₂. In other words, to induce producers and consumers to reduce their CO₂ emissions by one-half, policymakers would have to impose a carbon tax (or the regulatory equivalent thereof) of $130 per ton of CO₂, which would generate tax revenues totaling about $400 billion a year. The total resource cost of a 50 percent reduction in CO₂ emissions is about $180 billion a year, which is slightly less than 1 percent of world output at current price and output levels.

The incremental costs of reducing CO₂ emissions rise rapidly because no substitutes currently exist for many uses of fossil fuels. For example, transportation uses could achieve a large reduction in CO₂ emissions only if people traveled less or fewer goods were transported. Both of these solutions would be quite costly.

Forestry options. Several studies have proposed using trees to remove carbon from the atmosphere. Four interesting suggestions are to slow the deforestation of tropical forests; reforest open land, and thereby increase the amount of carbon locked into the biosphere; introduce a “tree bounty” to subsidize the sequestration of wood in durable products; and store trees indefinitely, in a “tree pickling” program.

¹⁶ The studies reviewed for this discussion included estimates based on specific technologies (such as CO₂ scrubbing and substitution of methane for oil and coal); econometric or elasticity analysis (often using highly aggregated models); and mathematical programming or optimization approaches (which often use activity-analysis specifications of energy technologies). For all three of these approaches, one can estimate the cost of reducing CO₂ emissions as a function of the penalty or tax imposed on those who emit CO₂. Note that all these estimates refer to the long-run cost—that is, the cost after the capital stock has fully adjusted. Attempts to reduce CO₂ emissions in the short run would be much more expensive. These costs do not include any adjustments for unmeasured or external environmental, health, or economic effects.
It has been estimated that deforestation in tropical forests adds 0.5 billion to 3 billion tons of carbon per year to CO$_2$ emissions (this amounts to 5 to 30 percent of total GHG emissions). Much deforestation is uneconomic in tropical regions even without the greenhouse effect. Therefore, if uneconomical deforestation was stopped, greenhouse warming could probably be slowed down significantly at little cost. The other three options would entail modest costs, but would only be marginally successful in reducing atmospheric concentrations of carbon.

*Overall costs of prevention.* It appears that a significant fraction of GHG emissions—perhaps one-sixth—can be eliminated at relatively low cost (figure 6-4). The most cost-effective way to slow greenhouse warming would be to curb CFC production and prevent uneconomic deforestation. Putting all the low-cost options together, I estimate that about one-sixth of CO$_2$-equivalent emissions can be reduced at an average cost of $4 per ton of CO$_2$ equivalent, for a total cost of about $6 billion a year.

To achieve further reductions in GHG emissions after the low-cost
options have been exhausted, it will be necessary to curb CO₂ emissions, say, through taxes or regulations on the carbon content of fuels. But a sharp reduction of GHGs quickly hits diminishing returns: a 50 percent reduction in GHG emissions in the long run will cost about $200 billion a year, which is about 1 percent of global output; attempts to restrict GHG emissions severely in the short run would be even more expensive.

It will be useful to compare these costs with historical events or regulatory programs. A low-cost program for slowing global warming (say one associated with the low-tax proposal in table 6-5 below) would impose a burden equivalent to a major U.S. regulation, such as those on drinking water, noise, or surface mining.¹⁷

The more stringent program to cut GHG emissions by half (associated with the high-tax scenario in table 6-5) would impose annual costs of around 1 percent of world output. This can be compared with the costs of all environmental, health, and safety regulations in the United States, which were estimated to cost 1 to 3 percent of GNP.¹⁸ Another parallel is with the impact of the energy price increases of the 1970s. Dale Jorgenson estimates that the energy price increase lowered U.S. output growth by 0.2 percent a year, or a total of about 3 percent, between 1974 and 1980.¹⁹ Charles Schultze found similar estimates for the effect of the first oil shock.²⁰

Adaptive Measures

Faced with the prospect of a changing climate, societies may decide to adapt. The key adaptations are by private agents—such as consumers and businesses. Decentralized adaptations—population migration, capital relocation, land reclamation, and technological change—will occur more or less automatically in response to changing relative incomes, prices, and environmental conditions.

Governments can also play an important role by ensuring that the legal and economic structure is conducive to adaptation. In particular, they can make sure that the environmental or climatic changes are reliably translated into the price and income signals that will induce

¹⁸ Litan and Nordhaus, Reforming Federal Regulation.
¹⁹ Verbal communication from Dale Jorgenson.
private adaptation. This may be difficult to do because markets do not set appropriate prices on most of the effects of climatic change. For example, greenhouse warming may alter the runoff patterns of major rivers, but water is allocated in such an archaic way that there is no guarantee of efficient allocation when water availability changes. Governments can improve adaptation by introducing general allocational devices (such as water auctions) that will channel resources to their highest-value uses. Similar issues will arise over the use of land near sea coasts and in floodplains.

Although adaptation and prevention are often treated as though they were the same solutions, they differ in one crucial respect: whereas preventive policies must generally precede global warming, adaptive policies will be taken as warming occurs. This point is crucial since cause precedes effect by a half-century or more. Immediate action is necessary to stabilize climate, while adaptations can wait for decades.

Although many people recognize that climate changes slowly, they often make the mistake of thinking about future climatic changes in the framework of today's world and ignore the inevitable social and economic evolution that will also take place in the coming decades. If, as suggested earlier, it takes eighty years or more for CO₂ to double, adaptations will be spread over a similar period. Yet social and economic structures will change enormously over that time. Think of how much the world has changed since 1910. That was the age of empires, when the Ottoman, Austrian, and Czarist regimes ruled much of Eurasia. The map of Europe has been redrawn three times since 1910 and is being restructured again. The power density of the United States was about 1½ horsepower per capita as opposed to 130 horsepower per capita today; one-sixth of the horsepower was produced by the 21 million horses in use, which were the leading polluters of the time. Air conditioning, nuclear power, electronics, and computers were unheard of.

Consequently, it would be foolish to prescribe adaptive steps now to smooth the transition to climatic changes over the next century. The time scale of most adaptations is much shorter than the time scale of climatic change. CO₂ doubling will take place over the next century, whereas financial markets adjust in minutes, product prices in weeks.


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labor markets in a few years, and the economic “long run” is usually reckoned at no more than two decades. To adapt now would be akin to building a Maginot Line in 1935 to cope with the military threats of the 1990s.

When adaptation is viewed in this light, it seems unwise to undertake costly adaptive policies unless (a) they have such long lead times that they must be undertaken now to be effective; (b) they would clearly be economical even in the absence of climatic change; or (c) the penalty for delay is extremely high. By these criteria, the only effective adaptive measures that surely can be taken now are to promote a healthy economy, strive to internalize most external effects to ensure an appropriate response to changing climatic signals, and raise the national saving rate to provide the investments needed for changing infrastructure.

Policies to Slow Global Warming

The discussion up to now suggests that it is difficult to find large economic costs of climatic change. Even so, the prospect of a catastrophic change might justify taking steps to slow global warming. What should the United States do now to respond to the threat of global warming over the next century?

A Cost-Benefit Approach

On economic grounds alone, any policies that promise incremental benefits worth more than their incremental costs are worth undertaking. As I mentioned earlier, it is useful to define policies as carbon taxes that penalize emissions of greenhouse gases in proportion to their global warming potential. These “taxes” are in a sense a metaphor for explicit steps the government might take to reduce GHG emissions through energy or gasoline taxes, CFC bans or regulatory limits, prohibitions on tree cutting, taxes on carbon emissions, or energy-efficiency standards.

Using the damage estimates outlined above and assuming a low

23. The analysis that follows ignores any relationship or “tie-in” between policies to slow global warming and policies to correct other economic or environmental problems. In fact, these relationships are often quite significant. For example, reducing CFCs is aimed primarily at countering ozone depletion, reducing oil consumption will improve the trade balance, and reducing coal consumption will reduce acid precipitation and other kinds of air pollution. These reinforcing effects are omitted here because the analysis examines appropriate policies to combat global warming; any further effects should be analyzed separately and added to or subtracted from the appropriate policies discussed here.
TABLE 6-5. Measures of Effects of Different Carbon Taxes*

<table>
<thead>
<tr>
<th>Sector of effect</th>
<th>Level of stringency of GHG reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low tax</td>
</tr>
<tr>
<td>Tax effect</td>
<td></td>
</tr>
<tr>
<td>Tax on CO₂ equivalent (per metric ton carbon)</td>
<td>5.00</td>
</tr>
<tr>
<td>Effect on fossil-fuel prices (1989 prices)</td>
<td></td>
</tr>
<tr>
<td>Coal price</td>
<td></td>
</tr>
<tr>
<td>Per metric ton</td>
<td>3.50</td>
</tr>
<tr>
<td>Percentage increase</td>
<td>10</td>
</tr>
<tr>
<td>Oil price</td>
<td></td>
</tr>
<tr>
<td>Per barrel</td>
<td>0.58</td>
</tr>
<tr>
<td>Percentage increase</td>
<td>2.8</td>
</tr>
<tr>
<td>Gasoline price</td>
<td></td>
</tr>
<tr>
<td>Per gallon</td>
<td>0.014</td>
</tr>
<tr>
<td>Percentage increase</td>
<td>1.2</td>
</tr>
<tr>
<td>Overall effects</td>
<td></td>
</tr>
<tr>
<td>Estimated percentage reduction of GHG emissions (CO₂ equivalent)</td>
<td>13</td>
</tr>
<tr>
<td>Total tax revenues, U.S. (billions)</td>
<td>10</td>
</tr>
<tr>
<td>Estimated global net economic benefits (++) or costs (−), billions of dollars per year, 1989 global economy</td>
<td>12</td>
</tr>
</tbody>
</table>

* Source: Nordhaus, "To Slow or Not to Slow."

a Figures do not take into account the reduction in GHG emissions in response to carbon tax, that is, they are "without feedback."

b Assumes a discount rate equal to 1 percent in excess of the growth of output and damages from a CO₂ doubling equal to 1 percent of global output.

discount rate on future damages from climatic change, I calculate that an efficient policy would impose a penalty on GHG emissions of about $5 per ton of CO₂ equivalent.  This tax or penalty would lead to a total reduction in GHG emissions of about 13 percent, which would include a large reduction in CFCs and a small reduction in CO₂ emissions. Such a tax would amount to $3.50 on a ton of coal, 58 cents on a barrel on oil, and 1.4 cents on a gallon of gasoline (table 6-5). U.S. revenues from a carbon tax of $5 per ton would amount to about $10 billion annually. I also show the impact of a more severe restraint—$100 per ton of CO₂—which would be close to the tax required to reduce CO₂.

24. The estimate of the "efficient" policy or tax is obtained by combining the estimated costs of reducing GHG emissions and the estimated damages from climate change. The best policy is a tax or restraint on GHGs beyond which the incremental costs of further restraints exceed the incremental benefits of reducing damages from climate change.
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emissions by one-half. The high-tax strategy would clearly have a major impact on the U.S. and global economies.25

Realistic Complications

A simple economic cost-benefit analysis is a useful way to start assessing possible actions, but it overlooks two practical questions that complicate policy enormously: how to discount future costs and how to allow for uncertainty.

Discounting future climate damages. The question of how to discount the costs of future climatic change in making current decisions is a particularly thorny one because the atmospheric residence time of CO₂ is hundreds of years. In part, discounting involves an ethical question about the relative valuation of the well-being of current and future generations. But a discount rate on climatic change cannot be chosen arbitrarily and without regard to other decisions. A rate close to the return on capital in most countries—say, 8 percent a year or more—would imply that one should forget about climatic change for a few decades.

In contrast, a low discount rate—say, 4 percent a year or less—would give considerable weight today to climate changes in the late twenty-first century. But such a low discount rate implies that other investment opportunities have been exhausted—hardly an attractive assumption in a capital-starved world. A low discount rate on climatic change along with a high return on capital is simply inconsistent. Faced with the dilemma of a low social discount rate and a high return on capital, the efficient policy would be to invest heavily in high-return capital now and then use the fruits of those investments to slow climate change in the future.

Uncertainty. Clearly, the debate on global warming is rife with uncertainty—about future emissions paths, about the GHG-climate linkage, about the timing of climatic change, about the impact on flora and fauna, about the costs of reducing emissions, and even about the

25. See William D. Nordhaus, “To Slow or Not to Slow: The Economics of the Greenhouse Effect,” paper prepared for the 1990 annual meeting of the American Association for the Advancement of Science. This analysis assumes that the discount rate on goods and services exceeds the growth rate of the economy by 1 percent a year. If the damage from a doubling of CO₂ is 3/₄ percent of total output, then the efficient CO₂ tax is $3.20 per ton of CO₂ equivalent; if the damage is 1 percent of output, the efficient tax is $12.70 per ton. I choose $5 as an illustrative intermediate figure.
speed with which the uncertainties can be reduced. How should decisionmakers proceed in the face of such uncertainty: like generals or environmentalists who assume the worst case, or like cigarette manufacturers who assert that unproved is untrue?

One answer would be to take a “certainty equivalent” or “best guess” approach, ignore uncertainty and the costs of decisionmaking, and plunge ahead. The cost-benefit analysis performed above represents this approach. It is appropriate as long as the risks are symmetrical and the uncertainties are unlikely to be resolved in the foreseeable future. Unfortunately, neither of these conditions is likely to be satisfied for the greenhouse effect.

Risk asymmetry. Virtually all observers agree that the uncertainties of climatic change are asymmetrical; people are likely to be increasingly averse to climatic change the larger the change. To go from a 2° to a 4° warming is much more alarming than to move from a 0° to a 2° warming. The greater the warming, the further the climate moves from its current state and the greater the potential for unforeseen events. Moreover, it is the extreme events—droughts and hurricanes, heat waves and freezes, river flooding and lake freezing—that produce serious economic losses. As probability distributions shift, the frequency of extreme events increases (or decreases) proportionately more than the change in the mean. Whether the increases in unpleasant extremes (like droughts in the corn belt) will be greater or less than the increases in pleasant extremes (like frost-free winters in the citrus belt) is, like most questions about climatic change, unanswered.

In addition, most climatologists think that the chance of unpleasant surprises rises as the magnitude and pace of climatic change increases. One must go back 5 million to 15 million years to find a climate equivalent to what is likely to occur over the next one hundred years; the concentrations of GHGs in the next century will exceed levels previously observed. Climate systems are complex, and it is not known whether they have multiple locally stable equilibria. It is sobering to remember that the Antarctic “ozone hole” was a complete surprise.

Among the kinds of physical effects that have been suggested and cannot be ruled out by scientists today are extensive shifts of glaciers and a subsequent rise in sea level of twenty feet or more in a few centuries; drastic changes in ocean currents, such as the displacement of the Gulf Stream, that would alter the climates of Atlantic coastal communities; and large-scale desertification of the grain belts of the world. Climatic changes might also upset the delicate balance of bugs,
viruses, and humans as the tropical climates that are so hospitable to spawning and spreading new diseases move poleward. No one has demonstrated that these effects will occur. Rather, it seems likely that unexpected and unwelcome phenomena, like the Antarctic ozone hole, will occur more frequently under conditions of more rapid climatic change.

Learning. The threat of an unforeseen calamity argues for more aggressive action than a plain-vanilla cost-benefit analysis would suggest. However, the possibility that uncertainties about climatic change might soon be resolved argues for postponing action until knowledge is more sound. Most scientists believe that research can improve understanding of the timing, extent, and impact of climatic change and thus sharpen the ability to identify appropriate policies. The best investment today may be in learning about climatic change rather than in preventing it.

In attempting to prevent climatic change, decisionmakers could easily make some serious mistakes. Imagine that a massive nuclear power program had been mandated for twenty years, only to find that the technology was expensive and unacceptable. Learning to cope with the threat of climatic change includes not only improving the estimates of its consequences, but also performing research to develop inexpensive and reliable ways of slowing climatic change.

A Framework for Policy

In designing policies to slow global warming, government must first recognize that this is a global issue. Efficient policies cannot be devised unless all countries take steps to restrict GHG emissions. In order to induce international cooperation, the United States and other high-income nations may need to subsidize the actions of poor nations (say, to slow deforestation or to phase out CFC use). Unilateral action may be better than nothing, but concerted action is better still.

In view of the costs of global warming that have been identified, the world would be well advised to take three modest steps to slow the process and at the same time avoid any precipitous and ill-designed actions that it may later regret. First, a concerted effort should be made to improve understanding of the climate by better monitoring of the global environment; analyzing past climatic records, as well as the environmental and economic effects of past and future climatic change; and evaluating the steps that might be taken to slow climatic change. Great strides have already been made in this direction in the past two
decades, but further research is required to sharpen pencils for the tough decisions that will have to be made in the future.

Second, the United States should support research and development (R&D) efforts aimed at finding new technologies to slow climatic change—particularly energy technologies that have low-GHG emissions per unit of output. Very little is invested in such work at present because of a "double externality": private returns are less than social returns, both because the fruits of R&D are available to those who spend nothing on research and because the benefits of GHG reductions are currently worth nothing in the marketplace. More government support should also go toward developing replacements for fossil fuels. Inherently safe nuclear power, solar energy, genetic engineering, and breeding of better biofuels, as well as energy conservation, are particularly promising areas of research.

Third, policymakers should try to identify and accelerate the myriad sensible measures that would tend to slow global warming, often at little or no economic cost. For example, they could strengthen international agreements that severely restrict CFCs, take steps to slow or curb uneconomic deforestation, and try to slow the growth of the uneconomic use of fossil fuels, say, through higher taxes on gasoline, on hydrocarbons, or on all fossil fuels.

These three steps would suffice for today, but should it be desirable to press further, one more step might be worth taking. Global environmental taxes could be imposed on the CO₂-equivalent emissions of greenhouse gases, particularly on CO₂ emissions from the combustion of fossil fuels. A GHG tax on the order of $5 per ton of CO₂ equivalent would be a reasonable response to the future costs of climatic change. A carbon tax would be preferable to regulatory interventions because taxes provide incentives to minimize the costs of attaining a given level of GHG reduction, whereas regulations often do not. To reap the maximum advantage, a carbon tax should be part of an international agreement implementing a tax or restraint in all the major countries of the world.

Some would argue that carbon taxes in particular would be a sensible economic policy. The consumption of fossil fuels has many negative spillovers beside the greenhouse effect, such as local pollution, traffic congestion, wear and tear on roads, and accidents. In addition to slowing global warming, carbon taxes would discourage the consumption of fossil fuels, encourage R&D on nonfossil fuels, favor fuel switching to low-GHG fuels like methane, lower oil imports, reduce the trade and
budget deficits, and raise the national saving rate. Indeed, in the tax
kingdom, a carbon tax is the rara avis that increases rather than reduces
economic efficiency.

Although the arguments for a carbon tax are persuasive, I hesitate to
recommend it at the present time. Negotiating a global carbon tax would
be a daunting task even for a president who likes taxes. Reducing the
risks of climatic change is a worthwhile objective, but humanity faces
many other risks and worthy goals. In providing for the future, in
allocating investment resources, there is a long list of important targets—
factories and equipment, training and education, health and hospitals,
transportation and communications, research and development, housing
and environmental protection, population control, and curing drug
dependency. Reducing GHG emissions is yet another investment, the
goal of which is to prevent the damages from climatic change. Given
the numerous urgent economic problems around the world today, it is
difficult to justify devoting a much larger share of investment to this
area than the amount proposed above.

Current Policy Initiatives

How does this framework for policy compare with the approach
taken by the Bush administration? The current political concern about
greenhouse warming can be traced in part to the unusual heat wave of
the summer of 1988, which coincided with a growing scientific consensus
that greenhouse warming indeed posed a serious threat. Candidate
George Bush promised to move ahead vigorously on environmental
issues and endorsed action to slow global warming. Other heads of
government joined President Bush at the Paris summit in July 1989 in
recognizing the need for international cooperation to solve global
environmental problems.

The administration's policy on global warming was finally unveiled
in February 1990. In terms of the four sets of policy measures discussed
above, the policies are as follows:

1. Expand knowledge. The administration proposes a large expansion
in its funding of studies of “global climate change.” The programs it

26. The central political statement is found in President Bush's speech to the Inter-
governmental Panel on Climate Change at Georgetown University on February 5, 1990.
The 1990 Economic Report of the President contains an extensive discussion of the
scientific, economic, and policy issues. The details of the budget changes are contained in
the budget for fiscal 1991.
TABLE 6-6. Energy Research and Development Funds in Fiscal Year 1991 Budget, Budget Authority

<table>
<thead>
<tr>
<th>Budget category</th>
<th>Amount (millions of dollars)</th>
<th>Percentage change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fiscal 1990</td>
<td>Fiscal 1991</td>
</tr>
<tr>
<td>Total Department of Energy budget</td>
<td>16,423</td>
<td>17,480</td>
</tr>
<tr>
<td>Total, civilian applied research and development</td>
<td>1,298</td>
<td>1,057</td>
</tr>
<tr>
<td>R&amp;D on technologies with low-GHG emissions</td>
<td>415</td>
<td>436</td>
</tr>
<tr>
<td>Conservation</td>
<td>194</td>
<td>183</td>
</tr>
<tr>
<td>Solar, renewables, geothermal, other</td>
<td>138</td>
<td>175</td>
</tr>
<tr>
<td>Nuclear (reactor programs only)</td>
<td>83</td>
<td>79</td>
</tr>
<tr>
<td>R&amp;D on technologies with high-GHG emissions</td>
<td>883</td>
<td>621</td>
</tr>
<tr>
<td>Coal</td>
<td>829</td>
<td>566</td>
</tr>
<tr>
<td>&quot;Clean coal&quot;</td>
<td>554</td>
<td>456</td>
</tr>
<tr>
<td>Other coal</td>
<td>275</td>
<td>110</td>
</tr>
<tr>
<td>Oil and gas</td>
<td>54</td>
<td>54</td>
</tr>
<tr>
<td>Basic research</td>
<td>2,399</td>
<td>2,680</td>
</tr>
<tr>
<td>Basic physics</td>
<td>872</td>
<td>952</td>
</tr>
<tr>
<td>Superconducting super collider</td>
<td>219</td>
<td>318</td>
</tr>
<tr>
<td>Biological and environmental</td>
<td>418</td>
<td>436</td>
</tr>
<tr>
<td>Basic energy sciences</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnetic fusion</td>
<td>320</td>
<td>325</td>
</tr>
<tr>
<td>Other</td>
<td>570</td>
<td>649</td>
</tr>
<tr>
<td>National Science Foundation, basic research</td>
<td>1,651</td>
<td>1,853</td>
</tr>
</tbody>
</table>


recommends are largely scientific and, at $1.03 billion for fiscal 1991, they represent a 57 percent increase in outlays over the prior year.

2. Reorient energy research and development. Table 6-6 shows a breakdown of the administration's energy R&D budget for fiscal 1991. Although the overall budget of the Department of Energy is designated for a modest increase, civilian R&D programs will decline sharply; there will also be a large cut in fossil energy programs, but little change in low-GHG technologies after correcting for inflation. The reduction in conservation is puzzling given the importance of increasing energy efficiency.

3. Phase out the most powerful CFCs. The U.S. government has taken the lead in this important initiative, which is contained in the Montreal
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Protocol of 1987 that commits signatories to cut production in half by 1998. (Note that the decision to phase out CFCs was made in order to prevent ozone depletion; the impact on global warming is a welcome but serendipitous side effect.) Even with the Montreal Protocol in place, however, the climatic impact of CFC emissions is expected to rise over the next century.

4. Plant trees. The Bush administration also proposes a “plant-a-tree” program, with proposed outlays of $175 million annually, to plant a billion trees each year. I estimate this program will reduce annual global emissions of GHGs by about 0.01 percent.

On the whole, the government’s policy to date represents a reasonable response to the threat of global warming. The Bush administration has recommended a cautious approach and avoided measures that would set the economy on a path that could not respond flexibly to new information or emerging technologies. If only all national priorities were addressed this well!

Final Thoughts

The United States and other large industrial countries would be well served by continuing to pursue the first three goals outlined above—improving knowledge, investing in R&D in new technologies, and tilting away from greenhouse gases. This approach would prepare the world for whatever developments might unfold in the future—for a tightening of the screws if the threat of global warming accelerates or for a relaxation of policy if science or technology alleviates concerns.

But above all, I would leave policymakers with the following advice: The threat of climate change is uncertain. It may be large, and might conceivably be devastating. But we face many threats. And don’t forget that humans have the capacity to do great harm through ill-designed schemes, as the communist experiment clearly shows. Gather information, move cautiously, and fashion policies efficiently and flexibly so that you can respond quickly as new information becomes available on the gravity of greenhouse warming.