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SCIENTIFIC PERSPECTIVES ON THE GREENHOUSE PROBLEM

George C. Marshall Institute
Washington, D.C.

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PREFACE

This report is based on the technical literature relating to the climatic impact of increased greenhouse emissions and on discussions with several scientists actively involved in the technical problems of long-range climate forecasting. We are indebted to James Hansen of the NASA Goddard Institute for Space Studies for a highly informative briefing, and also to Albert Arking and Kenneth Schatten of the NASA Goddard Space Flight Center, T.M.L. Wigley of the Climate Research Unit of the University of East Anglia, Syukuro Menabe of the NOAA Geophysical Fluid Dynamics Laboratory, Robert D. Cess of the State University of New York at Stony Brook, Sabatino Sofia of Yale University and Michael Rampino of New York University.

We are particularly grateful to Drs. Menabe, Wigley, Arking and Rampino for extensive and enlightening discussions subsequent to the formal briefings.

We are also profited greatly from very interesting discussions with Robert Malone of Los Alamos Laboratory, Stephan Schneider, John Eddy and Gerald A. Meehl of the National Center for Atmospheric Research, Richard Lindzen of MIT, Michael McElroy of Harvard University and Wilmot Hess of the Department of Energy.

Finally, we wish to thank Sally Baliunas of Harvard University and Simon Worden of the U.S. Air Force for alerting us to the fact that stars with properties nearly identical to the sun have been observed to undergo variations of several tenths of a percent in luminousity, large enough to be climatically significant, and to Wes Lockwood of Lowell Observatory for transmitting to us data on variations of up to 0.4% in the luminosity of sun-like stars, which have not yet appeared in the scientific literature.

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I. THE GREENHOUSE PROBLEM

This study considers the technical issues involved in forecasting the intensity of the greenhouse effect — a warming of the earth produced by the presence of carbon dioxide and certain other gases in the atmosphere. These gases absorb heat that would otherwise escape into space, returning some of it to the earth's surface and raising the temperature on the planet. The gases that have this heat-absorbing property are called greenhouse gases, and their warming influence on the earth is called the greenhouse effect.

The focus of the study is the evidence for a significant rise in the temperature of the earth in the last 100 years, coincident with a substantial increase in the amount of carbon dioxide and other greenhouse gases in the atmosphere. The increased atmospheric concentration of these gases is apparently the result of human activities, such as the burning of coal and oil.

Several scientific groups have concluded that man-made emissions of carbon dioxide and other greenhouse gases are the cause of much or all of the rise in global temperatures that has been observed since the turn of the century. They predict that if the atmospheric concentration of greenhouse gases continues to increase as a result of the burning of fossil fuels and other human activities, the average temperature of the earth may rise in the 21st century by as much as 5° C, or 9° F. Such an increase might cause widespread drought in many agricultural areas and have a destructive impact on human life in many parts of the world.

Not all experts in the field of climate studies agree with these conclusions. However, a substantial body of scientific opinion considers the man-made greenhouse effect to be a serious concern that must be addressed.

IS THE GREENHOUSE EFFECT A NEW PHENOMENON?

The potentially harmful greenhouse effect resulting from human activities is a relatively small addition to a large, natural greenhouse effect that has warmed the earth for billions of years. This natural greenhouse effect — which is, of course, unrelated to human activity — comes largely from water vapor in the earth's atmosphere. Water vapor, like carbon dioxide, is a greenhouse gas; it partly blocks the return flow of heat coming up from the surface and atmosphere to space thereby warming the earth. Naturally occurring carbon dioxide in the atmosphere adds to the greenhouse warming produced by the water vapor, but its effect is much less than that of water vapor.

The greenhouse effect produced by water vapor and other gases occurring naturally in the earth's atmosphere has been highly beneficial to life on our planet. If it were not for this natural greenhouse effect, the average temperature on earth would be a chilly 0° F — well below freezing. The warming effect of the earth's greenhouse gases has raised the average global temperature by 60° F — from 0° F to 60° F. Sixty degrees Fahrenheit is a comfortable temperature as an average over the planet. In fact, it may be close to the optimum average temperature the earth could have, from the viewpoint of supporting life over the largest possible area of the globe.

REASONS FOR ADVOCATING PROMPT GOVERNMENT ACTION

The enhanced greenhouse warming produced by human activity will be no more than a few degrees, and quite small compared to the 60-degree natural greenhouse effect, but its consequences could be devastating in the short term. A temperature increase of

up to 5° C could lead to recurrent and severe summer drought in the midwestern states of the U.S. and other productive agricultural regions. Although opinion is divided on the matter, in the worst-case scenario a warming of 5° C might also break up the West Antarctic ice sheet, eventually, after several centuries, raising sea levels by as much as 15 feet. Large areas of New York City, Miami and other coastal cities and densely populated river deltas would be submerged, and the lives of hundreds of millions of individuals living in coastal areas all over the world would be disrupted.

Government officials in the U.S. and other countries have begun to address the need for major policy decisions dictated by these grim projections. Their concern is heightened by the fact that the warming caused by the greenhouse effect takes a long time to build up and may not be noticeable for several decades, but once it has developed, it may take centuries to eliminate. As a consequence, if corrective actions, such as cutting down on the burning of fossil fuels, are delayed until the full measure of the greenhouse warming is upon us, it may not be possible to ameliorate its destructive effects for centuries.

II. RELIABILITY OF THE PREDICTIONS

How accurate are the greenhouse forecasts? The basic statement that carbon dioxide and other greenhouse gases warm a planet is not in doubt. Venus, for example, has an enormous amount of carbon dioxide in its atmosphere — 60,000 times more than the earth — and the surface of Venus is also oven-hot, with an average temperature greater than 800 degrees Fahrenheit. A calculation of the greenhouse effect produced by the dense concentration of carbon dioxide on Venus indicates that this effect can explain the searing Venus temperatures. No other explanation known to planetary science is adequate to account for these high temperatures.

Mars also has carbon dioxide in its atmosphere; in fact, the Martian atmosphere, although relatively thin, is composed almost entirely of this greenhouse gas. As in the case of Venus, calculations of the greenhouse effect on Mars show that it is warmer by just about the amount that would be expected as a consequence of the carbon dioxide in its atmosphere.

Applying these results to the earth, we can be confident that an increase in the amount of carbon dioxide in the earth's atmosphere must raise the planet's temperature. But by how much? Scientists trying to forecast the amount of greenhouse warming resulting from the increase in man-made carbon dioxide face the problem that the man-made warming effect they are calculating is quite small compared to many natural warming and cooling effects that influence the earth's climate. To treat this small man-made effect accurately, they must be able to compute the natural changes in the earth's climate with great precision. When they attempt to do a precise calculation, they run into two difficulties — oceans and clouds.

INFLUENCE OF OCEANS ON FORECAST ACCURACY

Scientists forecasting the magnitude of the man-made greenhouse effect have found that their results are affected by the ocean currents which carry large volumes of water from one part of the globe to another. When the effect of these large-scale ocean currents is included in the calculations, the size of the greenhouse warming may be decreased.

In one representative case, in which the emission of greenhouse gases was assumed to increase at the equivalent rate of one percent a year (usually regarded as a realistic projection), the calculations showed that if the effect of ocean currents is not included, the entire globe warms up by roughly 2° C to 3° C over the course of the next 50 years. But when ocean currents are included, the northern hemisphere warms up by the same amount as before, but the southern hemisphere warms up by only 1° C.* The Antarctic Ocean hardly warms at all, and may cool slightly.**

The improvement in forecast accuracy resulting from the inclusion of ocean currents thus has an important practical consequence. It diminishes the probability of an eventual breakup of the West Antarctic ice sheet, accompanied by a rise of sea levels and flooding of coastal cities all over the world.

A possible breakup of the West Antarctic ice sheet with a consequent substantial rise of sea levels, although not expected for centuries and indeed a matter of dispute among the experts, is nonetheless among the most menacing potential consequences of the man-made greenhouse warming. Full allowance for the effect of ocean currents in the forecasts may remove this threat from the list of greenhouse dangers.

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* Eventually, the southern oceans must also heat up in response to the increased greenhouse effect, but this will probably take hundreds of years.

** S. Menabe, private communication.

INFLUENCE OF CLOUDS ON FORECASTS

Clouds are the second major problem area for the greenhouse forecaster. Clouds cover roughly half the area of the earth at any given time, shielding this large area from the sun's rays. As a consequence they have a cooling effect on the climate. Clouds also have a heating effect because, like greenhouse gases, they block the flow of heat to space from the earth's surface. However, recent satellite measurements have shown that this heating effect is outweighed by the cooling effect of the clouds.

Clouds create a problem for the greenhouse forecaster because the natural cooling effect they produce is ten times as large as the entire man-made greenhouse warming projected for the middle of the next century. Their heating effect — which is a natural greenhouse effect — is also considerably larger than the predicted size of the man-made greenhouse effect.

This means that a very small change in the earth's cloud cover and cloud heights can greatly change the actual greenhouse warming. Suppose, for example, that because of the greenhouse warming, more water evaporates into the atmosphere from the warmer oceans. That could mean that more clouds would form. But the increased cloud cover would cool the earth, partly offsetting the greenhouse warming. This would be an example of "negative feedback": the greenhouse warming produces more cloud cover; the increased cloud cover feeds back into the climate, and decreases the amount of the greenhouse warming.

On the other hand, suppose that fewer clouds form because, although the atmosphere has more water vapor, the warm air has a lower relative humidity. Consequently, the vapor is less likely to condense into cloud droplets. That would mean a decrease in cloud cover and, therefore, more sunlight reaching the earth's surface and warming the planet. In other words, a change in cloud cover produced by the greenhouse effect would itself enhance or magnify the effect. This would be a case of "positive feedback."

Because the effect of the clouds is roughly 10 times as large as the greenhouse effect predicted for the mid-21st century, a very small change in the cloud cover could either diminish the greenhouse warming by a large amount, or magnify it by a large amount, depending on whether the cloud feedback was negative or positive. But small changes in cloud cover are very hard to predict. Consequently, the cloud feedback is also very hard to predict with any accuracy.

Types of clouds and cloud heights are also very important for estimating cloud feedback, and again very difficult to predict with accuracy. The relatively low-altitude stratus clouds block incoming sunlight more effectively than they trap the outgoing heat from below, and hence tend to have a cooling effect. Higher-altitude, tenuous cirrus clouds, on the other hand, let more light through, but block the flow of heat from below, and tend to have a warming effect.

Most greenhouse forecasts show that the cloud feedback is positive. That is, the combined effect of changes in cloud cover and cloud height or cloud type, in response to a greenhouse warming, is to increase the amount of the warming.* But again, by how much? The scientific groups working on the problem differ by 300 percent in their estimates of the amount of extra greenhouse warming produced directly or indirectly by clouds. Some groups say the extra warming is small, while others say it is several degrees.

The practical consequences of these disagreements are very great. They constitute a large part of the difference between forecasts of up to 5°C of temperature increase in the mid-to-late 21st

* The studies show that fewer clouds are formed as a result of the warming because warm air has a lower relative humidity; thus, more sunlight penetrates, the earth is warmed, and the greenhouse effect is magnified. In addition, the clouds that do form tend to do so at higher altitudes. Since at the higher altitudes the cloud tops are colder, they radiate less heat to space, further increasing the greenhouse warming

century, and forecasts of a temperature increase of only 1°C.

The disagreement arises because the formation of clouds is a complex phenomenon. The different types of clouds — cirrus, cumulus, and so on — absorb heat from below differently, and reflect sunlight differently. Each scientific group working on the greenhouse problem has its own way of handling these complications, and arrives at a different answer.

POOR QUALITY OF REGIONAL FORECASTS

It is important for greenhouse forecasts to be able to predict not only the worldwide temperature trends, but also the climate changes in a region, such as western Europe or the U.S. midwest. Regional climate changes can be very different from the global climate trends. For example, an analysis of temperature records reveals that in the 1970s and 1980s, when the world as a whole became warmer, England and Europe became somewhat colder.

Unfortunately, the greenhouse forecast models do very poorly in attempts to calculate regional climates, even when the region is as large as a continent. One climate forecast used in greenhouse studies predicts, for example, that the July prevailing winds over Eastern Europe are westerlies, coming mainly from the Atlantic Ocean. Actually, these winds are known to be easterlies coming from the Eurasian land mass. This remarkable mis-prediction has major consequences for the climate of Europe, since, inter alia, winds from the ocean carry more moisture, and cause more rainfall, than winds blowing off the continent.

EFFECT OF AVERAGING OVER LARGE AREAS

When the computations leading to the greenhouse forecasts are carried out, it is assumed at the outset that the surface of the earth

can be divided into a number of small areas. Within each area, the temperature of the surface is represented by a single number, which is supposed to be the average temperature for that area. The humidity, cloud cover, height above sea level, and all other quantities affecting the climate also are represented each by one number for the area, which is supposed to be their average value for that area. This is done to diminish the amount of computing required for the forecast.

The trouble with this process of averaging over areas is that the "small" areas assumed in the greenhouse forecasts are not so small. In most forecasts used for the greenhouse problem, the areas used to describe conditions at mid-latitudes — in the U.S., and Europe, for example — are about 500 miles in extent.*

In the U.S., an area 500 miles across nearly spans the distance between Los Angeles and Albuquerque. Two such adjacent areas encompass the territory running from the Mexican border to Canada.

When areas used for averaging are as large as this, two completely different climate zones — for example desert and fertile farmland — can exist within a single area. But an "average" over desert and fertile terrain would yield a forecast useless to the inhabitants of either region.

Averages over large areas also reduce the climate impact of mountain ranges, which can be very great. A mountain range deflects the flow of air and often causes moisture to precipitate as rain. As a result, the windward side of the range is generally wetter than the leeward side. But when the average height above sea level is computed for an area, the mountains are spread out and flattened, often to the point of insignificance.

A forecast based on such mountain-flattening averages would predict little difference in climate between heavily forested Ore-

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* They are chosen to be that large because the computers available to climate forecasting groups do not have the speed and power needed to generate a more detailed forecast in a reasonable amount of time.

gon and the Nevada desert, because it would miss the effect of the Sierra and Cascade mountain ranges in dumping moisture from the Pacific on the west coast.

Most experts on climate forecasting agree that the computations used for current greenhouse forecasts have little or no capability for regional prediction. One demonstration of that fact can be seen in the fact that two independent greenhouse forecasts, yielding the same global temperature increase in response to greenhouse gas increases, can give contradictory regional forecasts.

COMPUTING DIFFICULTIES IN GENERATING ACCURATE FORECASTS

If the inclusion of ocean currents changes the greenhouse forecasts so markedly, why do most scientific studies of the greenhouse effect continue to ignore the effect of these currents? If averaging over large distances leads to inaccurate regional forecasts, why do greenhouse forecasters not average over smaller distances?

The reason is that averaging over smaller distances costs the forecaster very heavily in computing time. The amount of computing time required for a greenhouse forecast goes up sharply when the forecaster attempts to describe the earth and its atmosphere and oceans in more detail by breaking the globe up into small areas.

For example, if the forecasts are averaged over 250-mile areas instead of 500-mile areas, the computation takes eight times as long. A single 100-year forecast takes approximately 4 months when the areas are 500 miles across. If they were reduced to 250-mile areas, the forecast would take nearly three years.

These computing difficulties are exacerbated by the problem of the oceans. Exceedingly high resolution is required for an adequate treatment of ocean currents. The Gulf Stream, for example,

which has such an important effect on the climate of northern Europe, is less than 100 miles wide at its narrowest point. Describing such currents means dividing the ocean's surface into many areas, each no more than 100 miles across.

The oceans make up three-quarters of the area of the globe. An enormous amount of computing time would be required to generate a forecast with a description of the oceans as detailed as this. For example, if the size of the areas over which the currents are averaged is merely cut in half, the calculations become 16 times longer.*

If all the important questions about the greenhouse warming could be answered by two or three 100-year forecasts, the answers everyone is waiting for might be obtained in a reasonably short time — even though each forecast takes years — by dividing the workload among several computing groups.

But if the greenhouse forecasts are to make a useful input to policy decisions they must be repeated a large number of times, to determine how the greenhouse warming depends on different assumptions regarding such factors as the rate of consumption of coal and oil, increase in electrical power use and third-world economic growth. A great many computing runs are needed to answer these basic questions. With the limited computing power currently available to climate forecasters, decades would be needed to provide policy makers with the information they require.

Yet greater accuracy and reliability in the forecasts are essential, in spite of the heavy computing burden and lengthy computations that will entail. The forecasts do not appear to be good enough in their present form to provide a sound basis for decisions affecting the economies of the U.S. and other nations.

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* Normally, doubling the detail (and halving the area of averaging) leads to an eight-fold increase in computing time. The additional factor of two in this case comes from the fact that as the area over which the Gulf Stream is averaged diminishes, the velocity of the Gulf Stream increases proportionally.

IMPORTANCE OF ADDITIONAL COMPUTING POWER

Inadequate allowance for the effective changes in ocean circulation is a major source of uncertainty in the greenhouse forecasts. The inability to generate meaningful regional forecasts is another reason why these forecasts are not of much practical value at present, even for the limited purpose of sounding an alarm over the coming greenhouse warming.

Both problems would be ameliorated if the surface of the earth were broken up into considerably smaller areas — at the expense of a substantial increase in computing time.

As noted above, increased computing power will be helpful in meeting the need for more accurate forecasts. Computing power alone will not solve the problem of the regional forecasts, but it will enable the greenhouse forecast groups to represent mountains more accurately, and they will also be able to start experimenting with other changes needed to tune up the regional forecast capability of their climate models. At present, the greenhouse forecasters — forced to resort to averaging over areas that may span a quarter of a continent — cannot even make a start on that problem.

The bottom line is that greenhouse forecasts could be made both more accurate and more timely — and, therefore more useful to policy makers — if the leading climate forecasting groups had more powerful computing facilities for their work.

Supercomputers now on the market offer a 15-fold speed increase over the best computers now used by scientists working on the greenhouse problem. Even faster computers are under development. These supercomputers can diminish errors and uncertainties in the forecasts resulting from inadequate allowance for the effect of ocean currents. They will also allow greenhouse forecasters to make a serious attempt at accurate regional forecasts — an achievement not within their grasp at present.

Critically important policy decisions affecting the five-trillion-dollar U.S. economy depend on the reliability of the predictions

generated by the greenhouse forecasting groups. Their computing facilities are underpowered for the importance of the work being done. One hundred million dollars would purchase top-line supercomputer complexes for the four major scientific groups working intensively on the greenhouse problem. The expenditure would be a solid investment in the future of the economy.

NEED FOR MORE OBSERVATIONS AND BETTER PHYSICS

Computing power is one major requirement for better climate predictions. The other need, equally important, is for more observations of the actual conditions prevailing on the earth and in its oceans and atmosphere, and for monitoring of factors causing climate change, such as greenhouse gas concentrations, values of the "solar constant" and changes in the transparency of the atmosphere caused by volcanic eruptions.

Observations of the oceans are particularly important because the state of observational knowledge of the oceans is much poorer than that of the atmosphere. More complete data on the variation with depth of ocean temperature, salinity and currents are badly needed.

Moist Convection. These expanded programs for observing clouds, ocean currents and temperatures, and other climate-related properties are vital to the success of the climate forecasting effort. For example, how is heat carried from the ground up to space? Any calculation of global temperature increases due to carbon dioxide emissions must have a fairly accurate answer to that question. Yet the answer is not known very well.

What happens in a general way is that water evaporates from the earth's surface — mainly from the oceans — to form warm, moist air. The warm air expands and rises, carrying its warmth and moisture to higher altitudes.

As the air rises, it cools and condenses into water droplets, and

cumulus clouds form. The condensation of the water vapor into droplets of liquid water releases additional heat to the atmosphere. Eventually, the droplets collect into rain drops which fall to the surface, cycling the moisture back to the surface of the earth. However, the heat that was carried up stays in the atmosphere.

This process by which heat and moisture are transported to higher levels in the atmosphere is called "moist convection." Moist convection has an indirect but critically important consequence for the greenhouse effect. By carrying moisture to higher altitudes in the atmosphere, it leads to the formation of clouds. These clouds change the surface temperature because, as noted on page 7, they screen the earth from incoming sunlight, cooling the surface; but they also block the upward flow of heat to space, warming the surface. No one is certain what the net balance of heating and cooling is for the clouds created by moist convection.

Furthermore, when the earth begins to get warmer in the first stages of the greenhouse effect, both the process of moist convection and the clouds it generates are affected, and the balance of the heating and warming is shifted. Is the shift in the direction of more warming, which means the long-term greenhouse warming is increased; or is it in the direction of cooling, which means the long-term greenhouse warming is cut down?

These uncertainties in the size of the 21st-century greenhouse warming, which are associated with the complexities of moist convection, are only a part of the cloud problem. Clouds are formed in other ways than by moist convection, and each mechanism of cloud formation introduces its own uncertainties into the greenhouse forecasts. As noted earlier, attempts by several groups to deal with the effect of clouds on the greenhouse forecasts yield results that differ by as much as 300 percent.

There is some grounds for optimism that these cloud-generated uncertainties would be reduced if more information could be acquired on the types of clouds, and cloud heights, that arise under different conditions. Collecting this information should be a top-priority objective in greenhouse research in the next few years.

III. CURRENT STATUS OF THE GREENHOUSE FORECASTS

Several greenhouse forecasting groups have estimated the amount of warming that would result if the equivalent concentration* of carbon dioxide in the atmosphere were to double as a result of human activity — a condition that may be encountered in 30 to 50 years. As noted previously, their results for the long-term or "equilibrium" increase in the average temperature of the earth range from a lower limit of 1° C to an upper limit of 5° C, or roughly 2° F to 9° F.** This wide spread in the forecasts made by the different groups is mainly the result of differences in their treatment of clouds.

A greenhouse warming of 1° C — at the lower end of the predictions — could be partly or largely offset by natural climate changes unrelated to human activity. The natural cooling that occurred during the Little Ice Age of the 16th and 17th centuries represented a temperature drop of roughly 1° C relative to today's temperatures. If a natural cooling comparable to the Little Ice Age were to return in the next century, a greenhouse warming of 1° C would have the beneficial effect of ameliorating its destructive impact, leaving global temperatures within a degree or so of their present levels.

On the other hand, an eventual greenhouse warming of 5° C — at the upper end of the range of predictions — would lead to cat-

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* In addition to carbon dioxide, the greenhouse gases include methane, nitrous oxide, and chlorofluorocarbons. For simplicity, all are lumped with carbon dioxide and stated as an equivalent carbon dioxide concentration — i.e., equivalent in their impact on the climate.

** S.H. Schneider, *Science* 243, 771 (1989).

astrophic changes over large areas of the globe in the next century. These changes would be too large to be offset by any likely change in climate due to natural causes. Policy makers surely would undertake early action to forestall this development, if they were confident in the accuracy of the forecasts predicting the large effects.

It may be possible to achieve an accuracy that would warrant this confidence by the application of a heavier concentration of computing power, combined with global observations on the earth's clouds and oceans. At the present time, the greenhouse forecasts tell us only that a serious problem may exist — or it may not.

COMPARISON BETWEEN GREENHOUSE FORECASTS AND OBSERVED TEMPERATURE INCREASES

As noted, while the greenhouse forecasts point to the likelihood of a global warming, they cannot predict its size with confidence. However, the fact that the earth has already become appreciably warmer in the last 100 years apparently indicates that the greenhouse effect is already here, and that its size is substantial.

Carbon dioxide in the atmosphere has increased by about 25 percent since the Industrial Revolution, as the result of the burning of coal and oil, deforestation and other human activities. If the middle range of greenhouse forecasts is correct, this increase in carbon dioxide should have produced a temperature increase of roughly 0.5° C between 1880 and 1985. The temperature measurements show an increase in average global temperature by just the predicted amount of 0.5° C.

Figure 1 shows the comparison between the calculated greenhouse temperature rise and observed temperatures. The solid line in Figure 1 shows the global temperature change observed on land between 1880 and 1985, averaged over 5-year intervals, as compiled by Hansen and Lebedeff. The observed temperature increas-

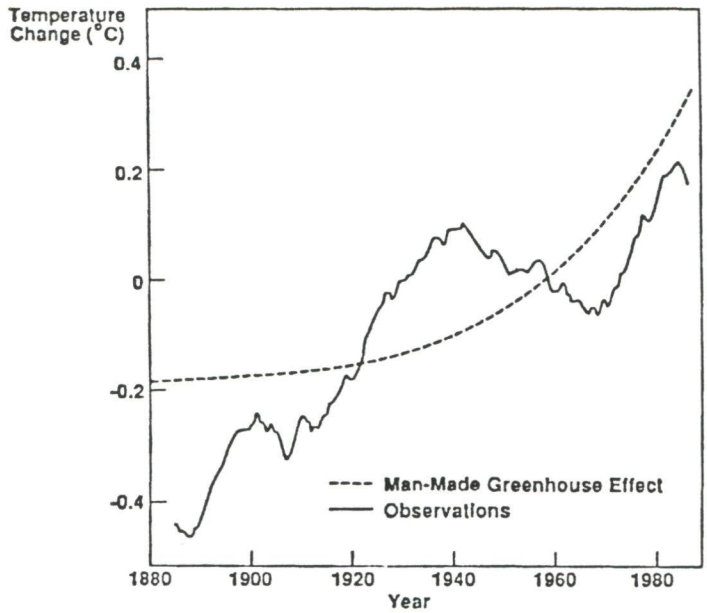

Figure 1. Comparison between observed global average temperature and calculations based on the greenhouse effect. The dashed line indicates the calculated temperature increase caused by the greenhouse effect since 1880. The solid line indicates the observed temperatures for the same period.

es by about 0.5° C between 1880 and 1985, as mentioned in the previous paragraph.

Similar results have been obtained by Jones and Wigley for land and ocean surface measurements combined, and by Folland and Parker from ocean surface measurements.*

The dashed line in Figure 1 shows the predicted greenhouse

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* Some experts have expressed skepticism regarding the reality of the 0.5° C rise in global temperature. Independent confirmation of the rise comes from recently reported findings that the sea level has risen by roughly one foot in the last 100 years. (W.R. Peltier and A.M. Tushingham, *Science*, 244, 806, 1989.) Calculations indicate that a sea level rise of just about this magnitude should accompany a temperature increase of 0.5° C. However, the authors of the report on the rise of sea level are careful to caution that their findings, while consistent with a 0.5° C global temperature increase, tell nothing about the cause of the increase.

warming during the same period. This curve is obtained from a calculation lying in the middle range of greenhouse forecasts, yielding a mid-to-late 21st century greenhouse warming of roughly 3° C. The dashed line also indicates a greenhouse temperature increase of about 0.5°C between 1880 and 1985.

EVIDENCE FOR A SUBSTANTIAL GREENHOUSE EFFECT

Several scientists interested in the greenhouse problem have remarked that the agreement between observations and the greenhouse predictions up to 1985 yields valuable information about the size of the long-time greenhouse warming expected for the 21st century. They point out that if the long-term greenhouse warming in the next century were very much larger than the current estimates suggest, we would have seen a temperature increase of substantially more than 0.5° C between 1880 and 1985.

On the other hand, if the long-term greenhouse effect were substantially less than the low end of the range of greenhouse estimates, it would not have produced the 0.5° C warming that has actually been observed in that period.

Some climate experts have concluded that the observed warming of 0.5° C tells us the middle range of greenhouse forecasts — a temperature rise of roughly 3° C in the mid-to-late 21st century — is roughly correct and should be a trustworthy guide to the full greenhouse warming that will occur in the 21st century.

IV. OTHER FACTORS INFLUENCING CLIMATE IN THE LAST 100 YEARS

A closer look at Figure 1, however, raises doubts about the accuracy of the greenhouse forecasts as a predictor of conditions in the 21st century. While the overall temperature increase in the greenhouse forecast agrees with the observed temperature increase of 0.5° C, the shape of the calculated greenhouse curve differs from the observations in important respects.

The greenhouse forecast (Figure 1, dashed line) shows a smooth increase in temperature with time, rising slowly at first and then more rapidly in recent decades. On the other hand, the observed temperatures (Figure 1, solid line) rose from the 1880s to around 1940. Then, although the concentration of man-made greenhouse gases in the atmosphere was now growing rapidly, the observed values dropped substantially between the 1940s and the 1970s.

Two aspects of this comparison seem significant. First, most of the rise of 0.5° C occurred in the first 50 years from 1880 to 1930, although less than a third of the total carbon dioxide increase occurred in that period. Second, no sign of the post-1940 drop in temperature appears in the greenhouse forecast for the period from 1940 to 1970, although this decrease was large enough to have a significant agricultural impact on Northern Europe.

The fall in temperature between 1940 and 1970 is particularly difficult to explain as a greenhouse phenomenon, because this entire period was one of strong economic growth and increasing emission of greenhouse gases. Even if allowance is made for a delayed response to the increased concentration of these gases, the

1940-1970 period should have been one of increasing temperatures — provided the greenhouse effect was the main driver of climate change in that period.

These departures from the calculated greenhouse temperature increase suggest that other forces besides the greenhouse effect have been influencing the earth's climate in recent decades.

VOLCANIC ERUPTIONS

What kinds of non-greenhouse forces could have been working on the earth's climate in the last 100 years? Volcanic eruptions are one possibility. Erupting volcanoes sometimes emit copious amounts of the gas sulfur dioxide, which become droplets of sulfuric acid in the atmosphere. The sulfuric acid droplets create a global haze that shields the earth's surface from the sun and cools the planet.

The global cooling produced by large eruptions can be substantial, of the order of several tenths of a degree. However, the particles that cause the cooling disappear from the atmosphere in a year or two, so that the climatic impact of even the largest eruptions is relatively brief.

Some experts say that many small volcanoes, erupting in succession in the 1940s and 1950s, could have caused a sustained temperature drop that would explain the post-1940s cooling. However, measurements of changes in the transparency of the atmosphere, shown in Figure 2 (p. 21), do not reveal any effect of this kind from 1914 to 1962. The atmosphere over that entire period was quite clear.*

Several volcanic eruptions did occur in the 1950s, but did not produce a global or hemispheric reduction in transparency and a consequent cooling effect. In some cases this was so because the eruptions were at high latitudes and their product did not enter

* M. Rampino and S. Self, private communication.

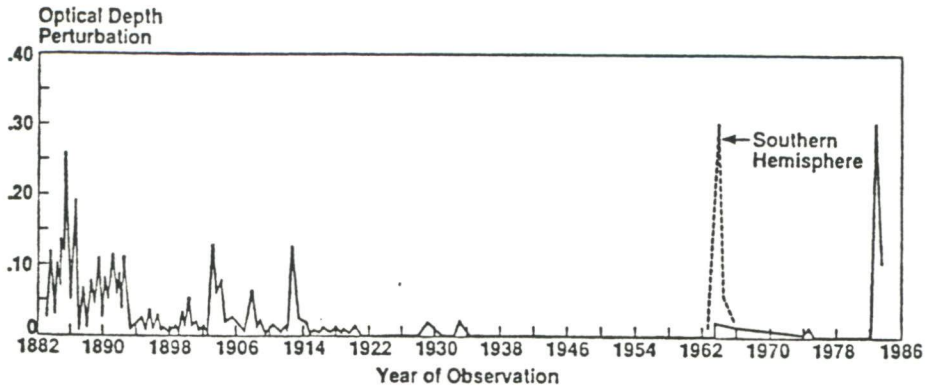

Figure 2. Observed changes in the transparency of the atmosphere, based on changes in the apparent brightness of non-varying stars. Two major volcanic eruptions of recent years — Mt. Agung in 1963 and El Chichon in 1982 — show up clearly as strong peaks. Very little volcanic obscuration of the atmosphere was observed in the 1940s and 1950s, contradicting the view that volcanoes caused the dip in temperatures commencing in the 1940s.

the mid-latitude circulation of the atmosphere. In two other cases — the large eruptions in Iceland in 1947 and Kamchatka in 1956 – – the eruptions not only were at high latitudes, but also produced relatively little sulphur dioxide, and so for two reasons did not add appreciably to the global haze of sulphuric acid droplets.

NATURAL VARIABILITY OF CLIMATE

The natural variability of the earth's climate is another possible explanation for the 0.5° C rise in temperature since 1880. Climate computations suggest that the earth's climate can undergo large swings in temperature that may last for several decades, and have no apparent cause. That is, the computed global temperature may vary by large amounts over decades, even if the computations hold constant the level of volcanic eruptions, concentration of greenhouse gases, changes in the sun's brightness and all other factors that would normally lead to a change in global cli-

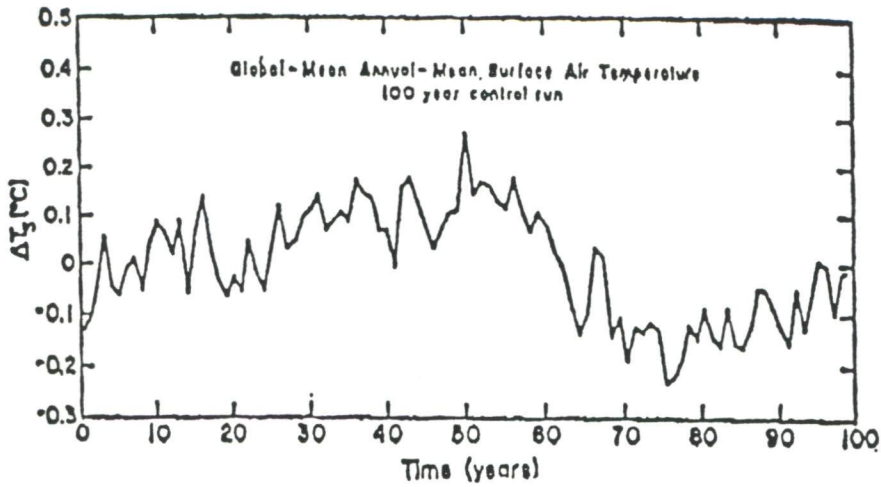

Figure 3. A 100-year computer run of global mean temperature. In addition to year-to-year fluctuations of about 0.1° C, the calculations show a 0.4° C drop over 25 years without known or obvious cause. This trend appears to be the product of a natural climate variability.

mate. This phenomenon of large and seemingly spontaneous changes in climate is known as the "natural variability" of the earth's climate.

Figure 3 shows the result of a 100-year computing run by Hansen et al., in which natural climate variability produced a significant change of roughly 0.4° C in temperature over 25 years, without any change in the so-called "forcing" terms, i.e., no changes in carbon dioxide concentration, solar energy output, volcanic activity or any other external agent.

Although the natural variation in this case happened to be a temperature drop rather than a rise, the implication in these results is that at other times the natural variability of climate might also produce a rise of 0.4° C, or even 0.5° C, over a comparable period.

It is important to note again that such variations in climate apparently can occur naturally, without any change in carbon dioxide concentration or other external "forcing" factors. Figure 3 is ev-

idence that much or all of the 0.5° C rise in temperature observed between 1880 and 1930 may be the product of natural variability rather than the greenhouse effect.

CHANGES IN THE SUN'S ENERGY OUTPUT

An increase in the sun's energy output is still another possible cause of the 0.5° C increase in temperature observed over the last 100-odd years. Climate calculations indicate that a temperature increase of 0.5° C could be produced by an increase of 0.3 to 0.5 percent in the total energy radiated by the sun to space.* Is it possible that the sun has grown brighter by 0.3 to 0.5 percent since 1880?

This idea that the sun's power could vary over intervals as short as years or decades has not been fashionable among astronomers and climate experts. However, recent findings in space science and astronomy have confirmed that such variations do occur. The possibility of solar energy changes on relatively short time scales, which was viewed until recently as an ad hoc conjecture without observational support, is now, because of these findings, an established astrophysical fact.

OBSERVATIONAL CONFIRMATION OF SOLAR CHANGES

The first of the new findings comes from satellite measurements of the sun's energy output, which can be made much more accurately than is possible from the ground. These measurements of the so-called "solar constant" — the amount of solar power per unit area reaching the earth — have revealed a decrease of about

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* T.M.L. Wigley, *Secular Solar And Geomagnetic Variations In The Last 10,000 years*, (Stephenson and Wolfendale, eds.), 209 (1988)

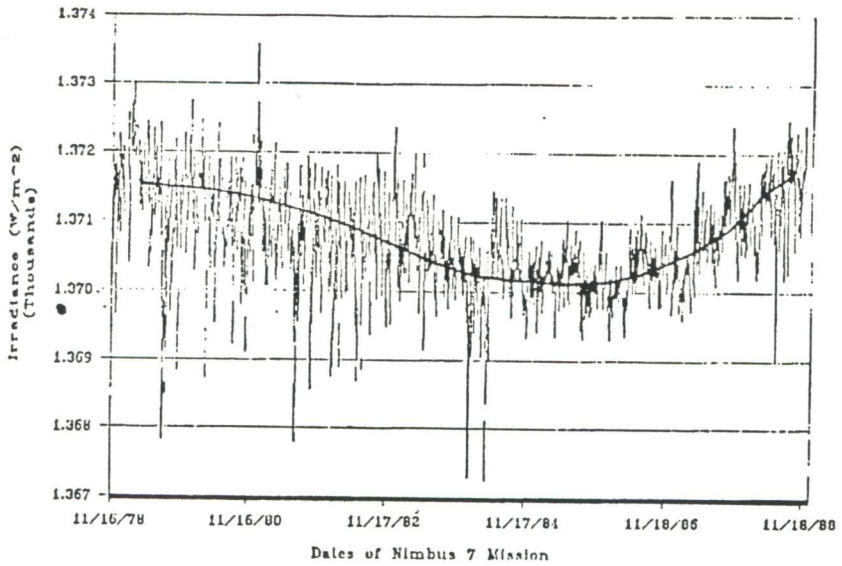

Figure 4. Changes in the solar constant between 1978 and 1988.

0.1 percent between 1978 and 1985, followed by an increase from 1985 to 1988.

Figure 4 shows the measured values of the changes in the solar constant between 1978 and 1988.

The satellite measurements prove that the sun's power does, in fact, change from year to year. It is now established that even on time scales as short as years or decades, the solar "constant" is not constant.

The measurements also show that the changes in the solar constant seem to follow changes in the number of sunspots observed during the sunspot cycle. When sunspots are most numerous on the face of the sun, the sun's energy output is greatest; when the sunspots decrease in number, the output of solar energy also decreases.

The measured change of 0.1 percent in the sun's energy output is not large enough to explain such changes of climate as the 0.5° C warming that occurred after 1880. As noted, that would require an increase of 0.3 to 0.5 percent in the solar constant. However, if a 0.1

percent change in solar energy output occurred in this one period of observation, it is possible that changes in the sun's output as large as 0.5 percent or more may occur at other times, or over longer periods of time.

Recent astronomical observations of stars have confirmed that such substantial changes in energy output do, in fact, occur in many stars similar to the sun. In a study of 36 such stars, Lockwood and Skiff found that nearly half varied by more than 0.5 percent in brightness over an interval of a little less than four years.*

Four among the varying stars were solar twins, almost identical to the sun in age, mass and other properties. Two of the four solar twins remained roughly constant over the four-year period, and the other two varied in brightness by 0.23 percent and 0.42 percent, respectively.

Figure 5 shows the variation in brightness from year to year observed in the latter two stars. Baliunas and Vaughan have found that one of the two variable stars also displays an eight-year cycle of surface activity similar to the sun's 11-year sunspot cycle (Fig-

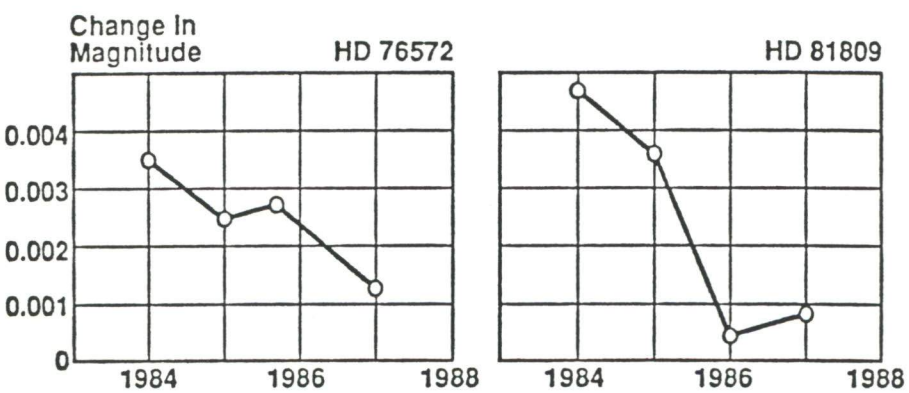

Figure 5. Changes of 0.23 percent (left) and 0.42 percent (right) in the brightness of two stars with nearly identical properties to those of the sun, over a four-year period.

* G.W. Lockwood and B.A. Skiff (Lowell Observatory), Air Force Geophysics Laboratory, Report AFGL-TR-88-0221 (1988)

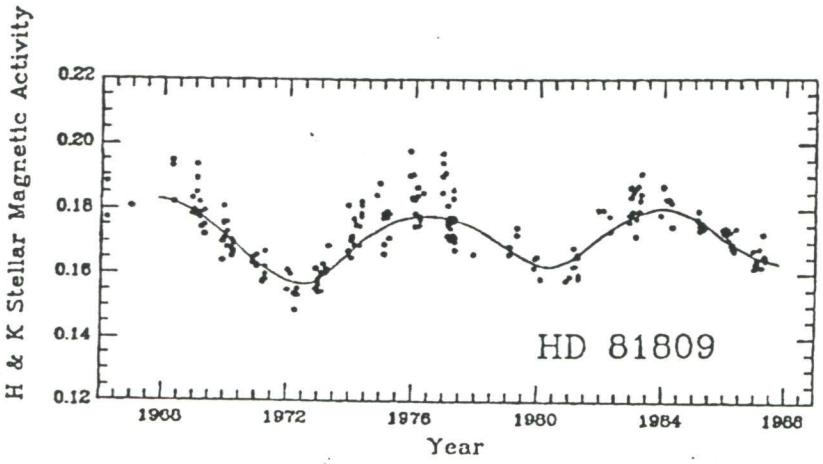

Figure 6. An 8-year cycle of changes in surface activity in HD 81809.

ure 6).* Comparison with Figure 5 reveals that, as in the case of the sun, when this star's surface activity declines, its brightness also decreases.

CHANGES IN SOLAR ENERGY OUTPUT AS A FACTOR IN CLIMATE CHANGE

Is the 0.5° C warming in the last 100 years the consequence of a man-made greenhouse effect?

As noted on page 19, the temperatures observed since 1880 have a pattern of change that does not resemble the temperature curve calcualted from the man-made greenhouse effect. However, they do resemble the changes in solar activity for the same period.

Figure 7 compares the changes in solar activity — represented by average sunspot numbers — to the changes in global temperature from 1885 to 1985. When solar activity increased between the 1880s and the 1940s, global temperatures also increased. When solar activity declined between roughly 1940 and the 1960s, temperatures also declined. When solar activity and sunspot numbers re-

* S. Baliunas and A. Vaughan, *Ann. Rev. Astron. Astrophys.* 23, 379 (1985)

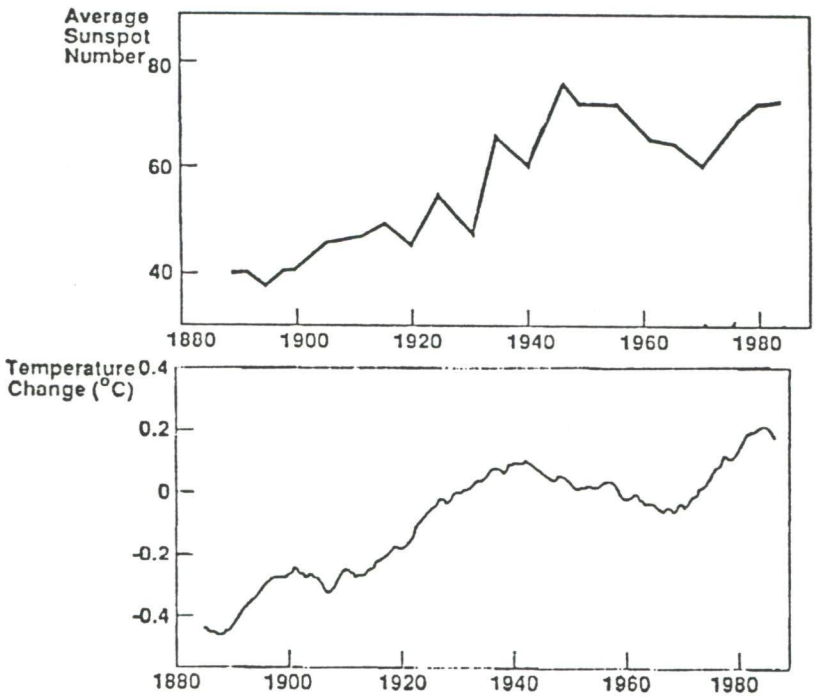

Figure 7. Comparison of (a) 33-year running average of sunspot numbers and (b) average global temperatures from 1885 to 1985.

versed and started to move up again, temperatures did the same.

These parallel patterns of change could be a coincidence, but they suggest a solar explanation for at least a part of the post-1880 temperature rise.

IMPLICATIONS FOR THE MAGNITUDE OF THE GREENHOUSE EFFECT

These findings on the climate impact of natural and solar variability have significant implications for policy makers considering today how to cope with the catastrophic greenhouse temperature

increase predicted for the mid-21st century.

Because of the wide spread in the amount of greenhouse warming predicted, and the difficulty in deciding which prediction is most accurate, scientists concerned with offering sound advice on the greenhouse problem have tended to rely on the observed temperature increase of 0.5° C since 1880 as their best evidence that the greenhouse effect is already here, and that steps should be taken now to cope with its full development in the next century.*

As noted on page 18, a greenhouse effect big enough to explain the post-1880 temperature rise of 0.5° C will probably produce a temperature increase of about 3° C in the mid-to-late 21st century. A temperature increase of this magnitude would be sufficiently serious to warrant consideration of early action by policy makers.

On the other hand, if some cause other than the greenhouse effect has produced much of the 0.5° C rise, and the greenhouse effect is responsible for only a small part of that rise, that means that we can expect a temperature increase of less than 3° C in the next century.

Suppose, for example, that some combination of natural variability and solar variability were responsible for 0.3° C of the 0.5° C increase observed since 1880. This would mean the greenhouse contribution is only 0.2° C. If that is the case, the mid-to-late 21st century warming will be only around 1° C.

This is considerably less than the warming of 3° C indicated by current mid-range greenhouse forecasts, which assume that the entire post-1880 rise of 0.5° C is due to the greenhouse effect.

In fact, it is possible that a combination of natural and solar variability is the cause of the entire temperature increase observed since 1880, with the greenhouse effect relegated to a negligible role.

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* "Since global climate models indicate the increase in greenhouse gases [in the past century] should have increased the temperature by 0.5° C, the modeling and observational evidence are consistent in indicating that the greenhouse effect is changing our climate." James Hansen, NASA Goddard Institute for Space Studies (*Washington Post*, February 11, 1989)

The effect of the wild cards introduced into the greenhouse studies by natural and solar variability is that 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.

V. EVIDENCE FOR NATURAL CYCLES OF WARMING AND COOLING

Is other evidence available that might be pertinent to a prediction of global temperatures in the 21st century? An analysis of climate records for England by Lamb indicates that during the last millenium, protracted periods of cold weather occurred roughly every 200 years — in the 13th, 15th, 17th, and 19th centuries. The best known of these cold periods was the Little Ice Age — a time of very low temperatures marked by failed harvests, famine and social upheaval in northern Europe. Temperatures in the Little Ice Age were roughly 1°C lower than they are today. The 1690s were perhaps the coldest decade on record in the history of Europe.

Wigley and Kelly have compiled additional evidence for the natural occurrence of cold periods every few centuries. Their climate history is drawn from global records compiled by Röthlisberger on the advance and retreat of glaciers.

The pattern of recurring cold periods reported by Wigley and Kelly on the basis of the glacial records is not as regular as Lamb's records. However, it has greater validity because the glacial data are global, while the Lamb climate record is regional and may be valid only for northern Europe.

Wigley and Kelly also discovered a correlation between the climate record and the record of solar activity going back over many centuries. The levels of solar activity were determined from measurements of the carbon-14 content of trees, compiled by Stuiver and Braziunas.* (See the appendix for an explanation of the

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* *Secular Solar And Geomagnetic Variations In The Last 10,000 years,* (Stephenson and Wolfendale, eds.), 245-266 (1988)

relation between carbon-14 and solar activity.) Comparing the carbon-14 record to their climate history, Wigley and Kelly found that six out of the seven most severe decreases in solar activity correspond closely to cold spells in the climate record. One of these is the famous period of about 50 years of very low solar activity in the 17th century, which coincided with the coldest period of the Little Ice Age.

Figure 8 shows the carbon-14 record during the last thousand years. The figure indicates surprisingly regular cycles of solar activity, with periods of low activity every 200 years or so during the last thousand years — midway between the 10th and 11th

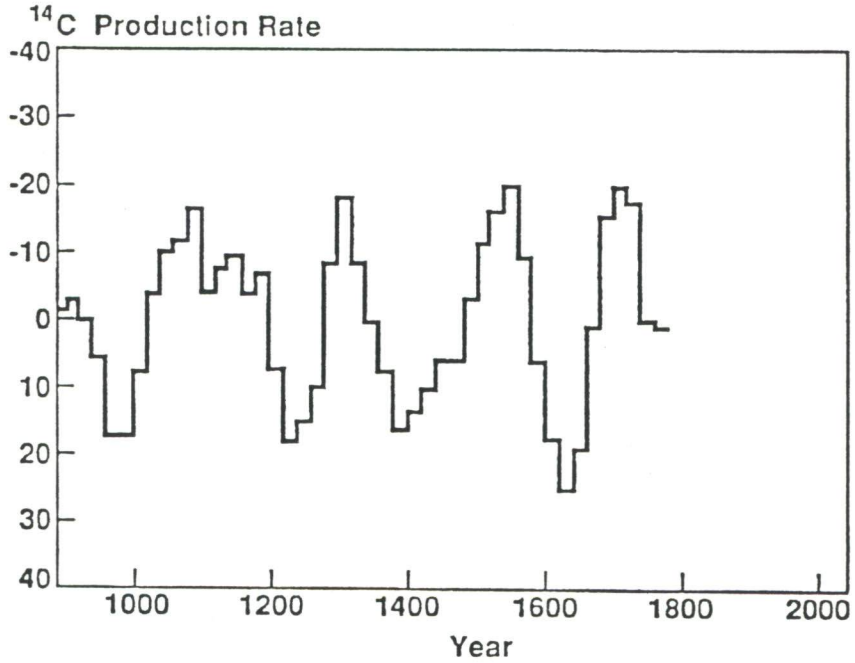


Figure 8. Anomalies in carbon-14 production rates associated with changes in solar activity. The negative of the production rate is plotted so that periods of low solar activity appear as low points on the chart. Dates are moved back 50 years to correct for the residence time of carbon-14 in the atmosphere.

centuries, and in the 13th, 15th, 17th and 19th centuries.

The carbon-14 record shows only the beginning of the period of low activity in the 19th century, because the interpretation of the carbon-14 production rates become less reliable after ca. 1800. However, sunspot records confirm that a minimum of solar activity also occurred in the 19th century, followed by a rise in the 20th century to the current high level of activity.

On the basis of this record, another period of low solar activity can be expected in the 21st century. If the correlation between low solar activity and low temperature continues, we can also anticipate a period of protracted cold in the 21st century as a result of the natural forces of climate change. If the 21st-century cooling is comparable to the Little Ice Age, the earth will be about 1° C colder as a result of natural factors alone than it has been in the 1980s.

VI. CONCLUSIONS

The fact that in the last 100 years, temperature and solar activity have followed a parallel course suggests that solar variability may be a significant part of the explanation for the post-1880 temperature rise of 0.5° C, and the greenhouse effect may be a relatively small contributor to the 0.5° C increase. In that case, the greenhouse effect that develops in the 21st century will also be relatively small — in the neighborhood of 1° C, rather than 3° C or more. A greenhouse warming of this magnitude could be partly or largely offset by the natural cooling expected in the 21st century. The balance of these man-made and natural forces of climate change would leave the world's climate within a degree or so of its present temperature.

RECOMMENDATIONS

Current forecasts of the man-made greenhouse effect do not appear to be sufficiently accurate to be used as a basis for sound national policy decisions. Policy makers would be wise to invest in the additional resources needed to improve the reliability of greenhouse forecasts before undertaking corrective programs that could turn out to be unnecessary — or even harmful if a substantial natural cooling occurs in the 21st century.

Procurement of top-line supercomputers for the major greenhouse forecasting groups could significantly diminish the level of uncertainty in the greenhouse forecasts by improving the treatment of clouds and oceans — the major unknowns in the present

forecasts.

The increased detail achievable with more powerful computers would also lead to information on regional climate changes — in particular, the occurence of regional droughts — which cannot be predicted with any useful degree of accuracy by the crude models currently in use.

The total cost of supercomputing facilities would be no more than $100 million. The investment would be cost-effective when viewed in the perspective of the large and potentially negative impact on the five-trillion-dollar U.S. economy, that could result from a premature decision based on inaccurate and possibly misleading forecasts.

The reliability of the greenhouse forecasts also suffers from gaps in observational coverage of clouds and oceans, and a poor understanding of certain processes vital to the determination of climate, such as moist convection. A stronger effort in global observations, and augmentation of the pitifully small force of scientists attempting to make progress on this important problem, are as important as the provision of computing power.

However, observations and personnel alone will not suffice to resolve the difficult public policy issues posed by the poor reliability of current forecasts. Number-crunching power is also essential.

Certainty will never be achieved in a matter as complex as the forecasting of climate for the coming century. However, it is our judgment that if a prudent investment is made in computing power, observing programs and added manpower, answers that have a usable degree of reliability can be provided for policy makers within 3 to 5 years. Through such an investment, the government can accelerate the pace of climate research to yield the necessary information in years rather than decades, so that timely action can be taken if needed.

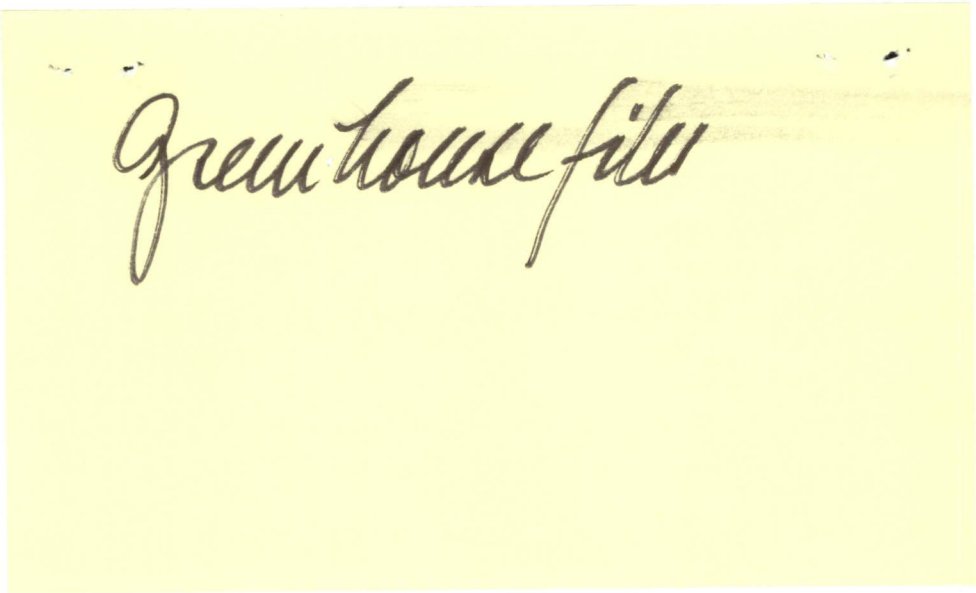
APPENDIX:
CARBON-14 AND SOLAR ACTIVITY (Page 31)

Carbon-14 is made by cosmic rays striking the earth's atmosphere. During periods of peak sunspot activity, when the surface of the sun is very disturbed, solar particles and magnetic fields spread through the inner part of the solar system, deflecting cosmic rays and tending to keep them from the earth. As a result, during these times of vigorous solar activity the amount of carbon-14 made in the earth's atmosphere decreases.

During quiet periods in the sun, when sunspots decrease in number or disappear (e.g., the Maunder Minimum of the 17th century), the intensity of the sun's magnetic field decreases in the inner region of the solar system .

Some carbon-14 atoms made by cosmic rays reach the ground and are incorporated into the bodies of trees in the normal process of tree growth. Analysis of the carbon-14 content in a cross section of a tree trunk yields a picture of carbon-14 changes during the tree's lifetime. The resultant curve of carbon-14 abundance versus time is a measure of variations in sunspot numbers and solar activity over time.

The chart plots the negative of the variations in carbon-14, so that a minimum in the carbon-14 chart as plotted here also means a minimum in solar activity and sunspot numbers. Since carbon-14 atoms typically take many decades to reach the ground, for the purpose of comparison with times of occurrence of climate changes the carbon-14 record shown in the chart has been shifted back 50 years.



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EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF MANAGEMENT AND BUDGET
Washington, D.C. 20503

JUN 14 1991

LEGISLATIVE REFERRAL MEMORANDUM

LRM #I-816

TO: Legislative Liaison Officer -

AGRIC-CR - Cindy Ayers (all testimony) - 447-9201 - 230
COMMERCE - Michael A. Levitt - 377-3151 - 324
DEFENSE - Samuel T. Brick, Jr. - 697-1305 - 325
INTERIOR - Pam Somers - 208-6706 - 329
JUSTICE - Paul McNulty - 514-2061 - 217
STATE - Will Davis - 647-4463 - 225
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CEA - Francine Obermiller - 395-5036 - 242
CEQ - Larry Flick - 395-5750 - 256
EPA - Thomas C. Roberts - 382-5414 - 326
NASA - Martin P. Kress - 453-1948 - 219
NSF - Charles H. Herz - 357-9435 - 248
OSTP - Damar Hawkins - 456-6272 - 288

SUBJECT: ENERGY Proposed Testimony RE: HR 1301, "National Energy Strategy Act"

This testimony deals with the effect of the National Energy Strategy on Greenhouse Gas Emissions

DEADLINE: 12 NOON JUN 17 1991

The Office of Management and Budget requests the views of your agency on the above subject before advising on its relationship to the program of the President, in accordance with OMB Circular A-19.

Please advise us if this item will affect direct spending or receipts for purposes of the "Pay-As-You-Go" provisions of Title XIII of the Omnibus Budget Reconciliation Act of 1990.

Questions should be referred to **Holly FITTER (395-6194)**, the legislative analyst/attorney in this office or to **Norman HARTNESS (395-6840)**.

28 pages attached

You may respond to this request for views by: (1) faxing us the attached response sheet; (2) if the response is simple (e.g., concur/no comment), leaving a message with the secretary of the above-named analyst/attorney; (3) calling the analyst/attorney; or (4) sending us a memo or letter.

E. H. Watts for

RONALD K. PETERSON for
Assistant Director for
Legislative Reference

CC:
M. Buegg
J. Fellows
E. Watts
A. Fraas
T. Gorman
H. Williamson
C. G. Gray/J. Holmstead

STATEMENT

OF

PETER B. SABA

PRINCIPAL ASSOCIATE DEPUTY UNDER SECRETARY

FOR POLICY, PLANNING AND ANALYSIS

DEPARTMENT OF ENERGY

BEFORE THE

U.S. HOUSE OF REPRESENTATIVES

COMMITTEE ON ENERGY AND COMMERCE

SUBCOMMITTEE ON ENERGY AND POWER

WEDNESDAY, JUNE 19, 1991

Barbie Campbell 586-8238

Thank you for this opportunity to provide the Department of Energy's views on potential global climate change and how the National Energy Strategy (NES) can reduce America's future greenhouse gas emissions.

In your letter of invitation, you asked that we discuss:

- How should the risk of climate change be considered in Congressional development of energy legislation?
- What elements of energy legislation will do most to reduce the risk?
- What measures will do most to increase the risk?
- Should we take any measures that are not being considered for energy security reasons?
- The Department's views on the recommendations of the National Academy of Sciences report, "Policy Implications of Greenhouse Warming."
- The Department's views of implementing a CO2 allowance offset program as proposed in last year's H.R. 5966.

Considering the Risk of Climate Change Impacts

The Department of Energy (DOE) has been active in research and analysis of climate change issues since 1977. Over 30 DOE scientists and other staff participated in the United Nations Intergovernmental Panel on Climate Change (IPCC) assessment of the science, impacts and appropriate response strategies to potential climate change. The IPCC determined that, despite the substantial scientific uncertainties, the world community should begin to reduce net "greenhouse gas" emissions by taking actions that are:

- beneficial for reasons other than climate change and justifiable in their own right;
- economically efficient and cost-effective;
- able to serve multiple economic and environmental purposes;
- flexible and phased so that they can be easily modified to respond to increased understanding of scientific, technological and economic aspects of climate change; and
- compatible with economic growth and the concept of sustainable development.

We believe that use of these criteria to select energy actions that are appropriate at present is a correct policy -- and matches the present Administration policy. Further, for energy-related actions, whether statutory or administrative steps, the President's National Energy Strategy provides a program of appropriate actions for the United States.

In releasing the National Energy Strategy in February, the President stated that this Strategy is built on a strong foundation of market reliance that harmonizes our energy and environmental objectives. After 18 months, 2,000 written submissions and testimony, and the most extensive public and interagency participatory process ever developed for shaping energy policy, we have unveiled a plan that will provide a long-term blueprint for our energy future.

The Strategy will increase energy and economic efficiency, reduce our vulnerability to disruptions in world oil markets, increase our electricity supply options, and improve the overall quality of our environment.

The National Energy Strategy, echoing the recommendations of the IPCC, includes a number of actions that, although taken principally for energy or national security reasons, will have significant environmental benefits, including curbing future U.S. emissions of greenhouse gases. Some of these gases and their precursors also have other confirmed, harmful effects on the environment such as depleting the stratospheric ozone layer or contributing to acidic deposition. But the U.S. and other industrialized countries should not act alone. Every country contributes to greenhouse gas emissions. Thus, effective action to address these emissions must be international in scope, and each nation should consider its unique cultural, legal, and developmental factors, when considering options to reduce greenhouse gas emissions.

How the United States is Reducing Net Greenhouse Gas Emissions

The United States has been a leader in promoting a global solution to climate change as well as protecting the stratospheric ozone layer. Earlier this year, at the meeting of the United Nations Intergovernmental Negotiating Committee on Climate Change, we released an action plan that details what the U.S. is doing to reduce net greenhouse gas emissions. In this plan, titled "America's Global Climate Change Strategy: An Action Agenda", we provide the key elements for a successful global climate response strategy. It is worth reviewing the basic principles underlying this approach because they reflect the IPCC recommendations and are the basis for the Administration's approach to climate change issues in the National Energy Strategy and in other policy development areas.

Any successful global climate change strategy must be comprehensive, incorporating all relevant greenhouse gases, their sources and sinks. A comprehensive approach requires that a common currency be developed for analyzing the impact that our actions will have on potential climate change. As part of the IPCC process, an index of all gases as a measure of their impact on warming called "global warming potential" was developed. "Global warming potential" is a standardized measure of the contribution from each source, expressed in terms of carbon dioxide equivalents. A comprehensive approach provides flexibility for each nation to develop a diverse, innovative, cost-effective mix of measures to meet its global stewardship responsibilities in a manner tailored to its own domestic circumstances. Global warming potential provides us with a common yardstick for assessing the effectiveness of those measures.

Our global climate response must be long-term, taking into account the full range of social, economic and environmental consequences of proposed actions for this and future generations. Our response must be flexible, relying on a diverse set of actions (including market incentives) that can be adjusted as our knowledge improves. Finally, our actions must be integrated, and designed to involve all nations and reflect each nation's unique circumstances in the development of a global response.

As shown in Figure 1, the major greenhouse gases attributable to human activity include carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and chlorofluorocarbons (CFCs). The man-made sources include energy use and production, agriculture, industrial processes, and deforestation.

The U.S. Action Plan adopts a comprehensive approach in that it not only considers steps to reduce emissions from sources, but also provides for increasing the planting of trees (which absorb carbon dioxide) and conducting research on how to increase other greenhouse gas sinks. Other actions provided in the plan include:

- Implementation of the Clean Air Act Amendments, which will increase energy conservation and reduce the buildup of precursor gases such as volatile organic compounds (VOC's) and carbon monoxide.

- The phaseout of CFCs that deplete the stratospheric ozone layer and contribute to potential warming. As a result of the Clean Air Act Amendments of 1990, these gases will be phased out faster than the Montreal Protocol requires.

- Implementation of a series of DOE energy efficiency and renewable energy initiatives that will reduce demand for energy and increase the potential for switching to non-greenhouse gas emitting options.

- A recently released EPA rule to control the emissions of volatile organic compounds and methane from landfills.

As a result of these actions, we estimate that U.S. greenhouse gas emissions in the year 2000 (measured in CO2 equivalents) will be at or below 1987 emission levels.

The National Energy Strategy Provides A Long-Term, Comprehensive Approach For Reducing Future Greenhouse Gases To Reduce The Potential Consequences of Climate Change

The National Energy Strategy expands the set of energy efficiency and lower greenhouse gas emitting options that are included in the Action Plan. The NES includes actions designed to increase energy efficiency in every element of energy production and use, provide cost-effective alternatives to burning fossil fuels for generating electricity, and increase the use of cleaner, more efficient alternative fuels and technologies that will reduce greenhouse gases produced from the transportation sector. These additional actions are expected to provide further protection against the potential for global climate change by reducing the expected U.S. greenhouse gas emissions associated with energy production and use.

A. NES Energy Efficiency Measures

The NES actions will improve energy efficiency in all sectors of the American economy.

- In the transportation sector energy efficiency will be improved by: (1) accelerated scrappage of older cars; (2) raising the limit on tax-free subsidies that employers can provide for mass transit; and (3) pursuing an aggressive program of research to develop new transportation technologies, including electric vehicles, high speed rail/mag lev trains, gas turbine engines, intelligent vehicle/highway systems and others. To fund this R&D, the President's FY'92 budget proposes $260 million to increase surface transportation efficiency, an increase of 60 percent over FY 1991 enacted levels.

- To promote alternative fuels and vehicles, we are proposing to (1) remove the cap on Corporate Average Fuel Economy (CAFE) credits for manufacturers of vehicles capable of operating on alternative fuels; (2)

accelerate the purchase of alternative-fueled vehicles for the Federal fleet; and (3) require that by the year 2000, 90 percent of new vehicle purchases for private, centrally-fueled fleets must be capable of using alternative fuels. These measures to increase the use of alternative fuels will provide important reductions in greenhouse gas emissions.

- In electricity, energy efficiency will be improved by: (1) increasing Federal support for integrated resource planning (IRP) (the FY'92 budget would increase funding for DOE's IRP program by 72 percent, from $2.9 million to $5 million); (2) providing tax-free treatment for discounts on utility bills provided for energy conservation investments; (3) developing and implementing energy efficiency standards for appliances; and (4) requiring energy efficiency labeling for various products, including light bulbs.

- In buildings, energy efficiency will be improved by: (1) increasing public housing energy efficiency; (2) devising and applying new building energy efficiency standards; (3) expanding the use of mortgage financing incentives for enhanced residential energy efficiency; and (4) improving energy efficiency in Federal facilities.

- To support these initiatives, we are, in FY 1992, requesting a 27 percent increase in funding for energy efficiency R&D over the 1991 level and a 60 percent increase from our last year's request.

B. NES Measures to Develop Energy Supplies That Generate Lower Greenhouse Gases

The NES will increase the availability of energy supply technologies with lower or minimal net greenhouse gas emissions. The actions include measures to promote natural gas, renewable, nuclear, and clean coal technologies. The NES would:

- Remove constraints to natural gas production, transmission, and use. This will be done through greater deregulation of natural gas pipeline rates and new gas pipeline construction options that do not require Federal certification. The NES also will encourage the use of natural gas as an alternative transportation fuel which will reduce CO_2 emissions.

- Promote renewable energy by: (1) reducing constraints to obtaining additional hydroelectric power from existing dams; (2) extending through 1992, the

investment tax credit for solar and geothermal electric energy technologies while continuing research and development efforts for photovoltaic, wind, solar thermal, biomass, and geothermal technologies; (3) developing biomass-based alcohol and alternative fuels from renewable energy-based feedstocks; and (4) expanding the use of waste to energy facilities. With these types of incentives, we project that renewable energy, producing little or no greenhouse gases, could significantly increase its market share by early in the next century.

- Make nuclear power a viable option for future electricity generation by: (1) improved licensing procedures; (2) development of standardized advanced light water reactor plant designs with improved safety and economic features; (3) public education programs; (4) comprehensive solutions to the high-level nuclear waste management problem; and (5) increased research and development on advanced technologies with passive safety features for two types of reactors. A number of unnecessary impediments must be removed in the near future to preserve contributions to greenhouse gases reductions now made by nuclear power generation and to provide added reductions relative to the current policies case after the year 2000.

- Provide incentives for the deployment of more efficient clean coal technologies that will emit less CO2. Many CCT are effective in reducing CO2 because they increase power generating efficiencies. In higher efficiency systems, less CO2 is produced per unit of fuel consumed. For example, technology like pressurized fluidized bed combustion (PFBC) and integrated gasification combined cycle (IGCC) boost generating efficiencies into the 40 - 45% range. This can reduce CO2 emissions by 17 - 27%. Future technologies such as fuel cells could lower CO2 emissions by up to 40%.

The NES Goes Beyond the Recently Announced "Action Plan" on Global Climate Change by Providing Long Term Emissions Reductions Relative to 1990 Levels

In developing the Strategy, we relied on projections of the future based on a set of assumptions regarding economic growth, fuel prices, productivity, etc. We developed a current policy base case and estimated the future impacts various NES actions would have on environmental quality, oil imports and electricity supply, among others. As the forecast period goes out beyond 2000, the certainty of the results of the Strategy decreases.

Without the NES, we project that emissions from one important greenhouse gas, CO2, could grow by nearly 90 percent by the year 2030. Methane emissions increase about 50 percent while the carbon monoxide and nitrogen oxide increases are similar to carbon dioxide.

Collectively, the NES actions would not only reduce our vulnerability to disruptions in oil supplies from unstable areas of the world, and increase our electricity supply options, but would also reduce the emissions of greenhouse gases from the levels otherwise projected. For most gases, these reductions are projected to fully offset increases otherwise expected from growth in the economy and population. Specifically:

- Actions as a result of the Strategy and current Administration programs should reduce the rate of growth of U.S. carbon dioxide and carbon monoxide emissions. After 2015, we project that these annual emissions rates will level off with subsequent annual emissions through 2030 being no higher than in 2015.

- NES actions, as well as EPA's regulation controlling methane from landfills, will reduce growth in U.S. methane emissions through 2015 from the current policy case. Further, after 2015 annual U.S. methane emissions from energy sources are projected to decline and by 2030 will be below 1990 levels.

- Administration actions, including those embodied in the NES, are projected to hold U.S. emissions of nitrogen oxide and volatile organic compounds to levels that are about the same or below the 1990 levels through 2015, with a decline in such emission levels expected after that time.

The Global Change Action Plan describes existing Administration actions that are projected to hold annual greenhouse gas emissions at or below 1987 levels in the year 2000 (measured in CO2 equivalents). As shown in Figure 2, when all the gases are considered and expressed in terms of global warming potential, the National Energy Strategy, coupled with existing Administration programs, is projected to hold annual U.S. emission levels at or below current levels well beyond the year 2000.

Our Appraisal of the NAS Report

The Department has reviewed the report by the Synthesis Panel of the National Academy of Sciences' Committee on Science, Engineering and Public Policy, Policy Implications of Greenhouse Warming.

The findings and recommendations of the panel appear to be, in general, consistent with those advanced by the Administration in its Action Agenda: America's Climate Change Strategy, and in the National Energy Strategy.

The areas of agreement between the NAS report and Administration positions extend across the full range of the NAS recommendations relating to greenhouse gas emissions. We are aggressively pursuing the phaseout of CFCs and other halocarbons under the terms of the Clean Air Act Amendments. As I discussed earlier, the NES contains a full roster of measures designed to foster energy conservation and efficiency. Our efforts under the NES to promote an energy supply mix that relies more heavily on cleaner technologies and alternative fuels matches closely the NAS recommendations relating to natural gas, nuclear energy, solar and other alternative energy sources. There is also substantial correspondence between the NAS recommendations regarding reforestation and our work under the America the Beautiful Tree planting program. Attached as Appendix A is a comparison of the mitigation options considered by NAS (as set forth in table 6.1 of the NAS Report) and related NES actions. In addition, attached as Appendix B is a listing of the energy policy recommendations contained in chapter 9 of the NAS Report and related NES actions.

We agree with the findings of the panel. We believe, for example, that their findings on how various impact categories may change due to climate change, (e.g., changes to coastal communities) and the probable ability and cost to adapt to such changes, are fully consistent with our views and those of the IPCC assessment report. Our calculations on how emissions intensity (emissions/energy output) will change due to NES actions is fully consistent with the range that the Academy panel calculated for their proposed initiatives to be taken at this time.

It is essential that you understand that we do not support, and we do not interpret the NAS report as advocating, a 10-40% absolute reduction in greenhouse gas emissions. The NAS concluded that their "analysis suggests that the United States could reduce its greenhouse gas emissions by between 10 and 40 percent of the 1990 level at very low cost." This range was based on a static analysis, predicated on current levels of economic activity, and made no allowance for population or economic growth over time. As explained in Fact Sheet 1, the National Energy Strategy, which is projected to result in greenhouse gas emissions remaining at or below 1990 levels through the year 2030, taking into account economic growth and sectoral changes. When analyzed on a comparable basis using emissions intensities, the NES would also reduce emission intensities within the 10-40% range consistent with Academy's findings.

Moreover, as Secretary Watkins noted when the report was released, the NAS did not call for limits on carbon dioxide emissions or for taxes on energy use.

Energy Legislation and Greenhouse Gas Emissions

Your letter of invitation to Secretary Watkins also asked us to discuss the impact of various legislative proposals on reducing the risk of climate change. While the Department would be happy to model specific bills on request, the variations on these proposals are too numerous to quantify for purposes of this testimony. Moreover, there is no one legislative silver bullet to address potential global climate change and the Administration does not believe that it is appropriate to judge legislation solely on its impact on potential climate change. Instead, we believe that energy legislation must be comprehensive and balance energy, economic and environmental goals, including the potential to reduce greenhouse gas emissions. We think that The National Energy Strategy Act (H.R. 1301) submitted by the Administration, The National Energy Security Act of 1991 (S. 1220) passed by an overwhelming majority by the Senate Energy and Natural Resources Committee, and The Comprehensive Energy Policy Act of 1991 (H.R.1453) as introduced by Congressmen Lent, Moorhead, et. al. represent examples of comprehensive energy legislation that balance energy, economic, and environmental goals while achieving significant reductions in greenhouse gases.

An example of the limitations of focusing on individual measures in a piecemeal fashion is the bill introduced by Senator Bryan that would substantially increase the corporate average fuel economy (CAFE) requirements for cars and light trucks sold in the United States. That bill would increase fuel economy levels for the new car fleet, on a percentage basis, to about 40 mpg by the end of the decade. While we do not believe that such CAFE levels are achievable from the standpoint of technology, cost, safety and economic practicability, if they were we estimate the bill would reduce CO_2 emissions from automobiles and light duty trucks operating in 2005 by 12.6%. This would translate into a 2.5% decrease in U.S. CO_2 emissions and a 0.5% decrease in global CO_2 emissions. Thus, at considerable cost the U.S. might have a fairly minor impact on global emissions. This would be done without knowing whether these emissions reductions are the most cost-effective and without knowing the impact on our international competitive position.

Our Views on H.R. 5966

You asked for the Department's views on last year's bill, H.R. 5966, introduced by Representatives Cooper and Synar. This bill would require new utility units and large industrial units, including existing units that undergo major modifications (as defined in Clean Air Act regulations), that emit or have the

potential to emit more than 100,000 tons annually of CO2 to obtain emission offsets. These offsets can be generated from a diverse set of sources. They include:

- reduced emissions in existing utility and large industrial fossil fuel units below their 1990 baseline CO2 emissions,
- net CO2 removed from the atmosphere by trees that were planted to offset CO2 emissions from new units,
- CO2 emission reductions from fuel switching in existing units,
- CO2 emission reductions from conservation and efficiency measures that go beyond regulatory requirements, and
- equivalent similar reductions in other greenhouse gas emissions.

Thus, the offsets can be from the same sector as the unit needing an offset or from different sectors.

The bill anticipates the selling and trading of these offsets although the initial recipient of the offset is not always clearly identified and would require the EPA Administrator to maintain National "Offset Bank" for recording and trading offsets.

We have reviewed H.R. 5966 and oppose its enactment because it fails to meet some of the key criteria for a successful global climate change strategy discussed above and goes well beyond the actions recommended by the IPCC or the National Academy. In short, this proposal is not comprehensive; mandates emission limits that are neither justifiable in their own right nor justifiable based on our current scientific understanding of potential climate change; and requires unilateral action by the United States thereby placing the United States at a competitive disadvantage relative to other countries while only having a minimal effect on worldwide greenhouse gas emissions.

First, the bill is not comprehensive because it targets only one greenhouse gas -- carbon dioxide -- and targets only <u>new</u> sources and only certain sectors. The comprehensive approach incorporates all relevant greenhouse gases, their sources and sinks, so that the maximum benefit to the environment can be achieved from any given investment in response strategies. Permitting offsets to be obtained from other sectors or by reducing other greenhouse gases is not the same as the comprehensive approach. While an allowance trading mechanism, if properly structured, has the potential to reduce compliance costs and increase the efficiency of a regulatory system, the offset mechanisms in H.R. 5966 at best would increase the efficiency of

a regulatory system that was fundamentally inefficient because it targets only "new major CO2 sources." H.R. 5966 in effect raises costs for new major CO2 sources, while permitting economic actors to shift to unregulated activities that could continue to contribute to potential climate change. There is no evidence that this represents a cost-effective approach to the risks of potential climate change.

Second, the mandatory emission limits on new CO2 sources are an inappropriate response to the potential risks of climate change given the current scientific uncertainties. Such limits are not justified in their own right, which is a fundamental criteria in the IPCC recommendations and is at the core of the Administration's policies that result in no growth of greenhouse gas emissions above 1990 levels. In addition, this bill would mandate actions that significantly exceed those recommended by the National Academy of Sciences. The Academy concluded that despite the great uncertainties, climate change is a potential threat sufficient to justify the taking of certain low-cost options now. As I indicated earlier, there is substantial congruence between the Academy's recommendations on energy policy and the Administration's National Energy Strategy. The Academy did not recommend setting limits on CO2 emissions and concluded that options requiring great expenses are not justified at this time.

The Administration believes that this statutory addition to the actions of the National Energy Strategy to reduce emissions of greenhouse gases from new electric utility powerplants and large industrial facilities is not justified. The actions that have been taken as documented in the U.S. Action Agenda plus the impacts of full implementation of the National Energy Strategy actions will significantly reduce potential risks of increased accumulation of greenhouse gases. The added step of a CO2 offset policy for new sources may reduce the effectiveness of NES actions in moderating emission growth trends. In addition, as discussed below, we have significant concerns about the energy implications of the bill, the costs imposed by the emission offset requirements, the system's administrative complexity, and its equity and efficiency.

Third, this bill would require unilateral action by the U.S., thereby decreasing U.S. competitiveness while only having a minimal effect on worldwide greenhouse gas emissions. The potential threat of climate change is a global issue requiring a global, integrated approach. The United States has taken a leading role in international global change research efforts and in international negotiations on climate change. No single country or limited group of countries can, in the longer term, have a significant effect on climate change by unilateral action. Legislating a CO2 offset program would significantly inhibit our Nation's flexibility in current international negotiations and

could prove to be counterproductive in achieving international agreement on a global, comprehensive approach.

Need for Additional Actions

Without the NES actions, the radiative forcing due to U.S. emissions would increase about 1 percent per year averaged over the 40 year period. Based on conservative estimates, the NES actions will cause the radiative forcing for United States' emissions for any year in the foreseeable future to be at or less than the contribution of U.S. greenhouse emissions in 1990.

The National Energy Strategy will be updated in the spring of 1993. Also, there could be advances in our understanding of global climate change and its projected impacts by that time, even though scientists tell us that considerable uncertainties will continue.

And, we hope that a framework convention on global climate change will have been signed by most countries by this time next year, as well as an international agreement to protect and enhance the globe's forested areas. One likely outcome of these new conventions would be the scheduling of follow-on negotiations on protocols to be added to these framework conventions.

Thus, it is clear that actions are taking place, both internationally and domestically, to address the concerns and uncertainties of global climate change and its potential impacts. There is need for international coordination to assure that effective, long-term, comprehensive and globally integrated programs follow the framework convention. Taking this process into account, we do not believe that imposing an extensive new regulatory program on new and modernized U.S. facilities is appropriate or prudent.

Adverse Impacts Due to Focus on New Sources

In addition, last year's H.R. 5966 creates incentives which will result in adverse market reactions because of the bill's focus on new sources. These reactions could weaken the results of the NES actions and the Clean Air Act Amendments that we anticipate would reduce greenhouse gas emissions, including emissions of carbon dioxide. We believe that adding H.R. 5966's requirements might increase the U.S. contributions to radiative forcing compared to what is otherwise projected to happen.

Note first that the bill would require CO2 emission offsets for <u>new</u> major CO2 sources. One way to escape this requirement, yet provide greater electricity generation or industrial output, is to increase the capacity utilization factor of existing facilities. Thus, utilities and major industrial units are provided a regulatory incentive to continue operation of older,

less efficient units rather than to modernize equipment, to adopt new, more efficient technologies and processes, and to dispatch lower emitting production units first. The probable high costs for purchase of offsets, especially in the early years of the program, will further stimulate choices by utility operators to maintain and operate the older units and will act as a significant disincentive to modernization of units and technologies.

Other Issues Raised by H.R. 5966

The bill raises a range of questions concerning equity, efficiency, and administrative complexity.

Ownership of Offsets

- Who is assigned the initial rights to these CO2 offsets? What is the rationale that they should be assigned to appliance manufacturers or auto manufacturers to sell the CO2 offsets to another sector?

- Should foreign manufacturers receive such offsets enabling them to sell to domestic powerplant operators? Could such offsets result in both a significant cash outflow from the U.S. and reduce energy security?

- Who would get these offsets, the manufacturers or the consuming individuals who are too diverse to accumulate offsets sufficiently to participate in the offset bank?

- Another question concerns the selective imposition of the offset requirement only on new utility units and large industrial plants, yet other sectors are allowed to accumulate and sell offsets. Should, for example, an automobile manufacturer that has fleet efficiency greater than CAFE earn offsets for sale; yet, the same manufacturer, if not achieving the CAFE, not be required to purchase CO2 offsets? Should an investment in energy conservation earn a credit, yet a comparable investment that results in energy use above the efficiency norm not be faced with an CO2 debit.

Impact on Energy Efficiency

- Would an offset system impede updating of efficiency regulations due to the value of offsets? Will the ability to sell offsets actually result in higher U.S. emissions since emission reductions by one corporation in one sector can be transferred to increase emissions in another sector at the same time as other corporations have increased greenhouse gas emissions in the sector where the offsets originated?

- At the present time, projections of CO2 trends, even for baseline scenarios, assume substantial gains in energy efficiency; won't the ability to sell CO2 offsets from energy conservation investments actually allow the emission reductions from these trends that were expected for economic efficiency reasons to be sold and thus increase total U.S. CO2 emissions above expected trend patterns?

Predictability of System

- Since availability of CO2 offsets can change as laws (e.g., on CFCs) or regulations (e.g., on appliances) are made more stringent, will these changes result in such instability in long-term availability of CO2 offsets for the offset bank? If this could occur, utilities could not count on long-term availability of CO2 offsets for purchase over the life of the new equipment and thus are not likely to modernize fossil energy facilities or build new, more efficient facilities.

Cost and Administration of System

- Another general point concerns the potential cost of the CO2 offsets. If the cost of offsets is on the order of $100 per ton of CO2 (the actual level cannot be predicted yet), the cost placed on fossil fuels is sufficient to approximately double the fuel cost. Yet, no similar cost increment is placed on the older units operating similar technology. Is it reasonable to impose such costs on an industrial plant, an independent power producer, or a utility because the facility operator is prepared to use new, probably more efficient production processes and equipment rather than continuing high utilization of older, possibly more polluting, and probably less efficient equipment?

Therefore, it is our belief that the CO2 offset program as proposed in H.R. 5966 is not appropriate. Further, even if the offset requirement was set on a consistent basis for new and old units, we believe that the planning for and securing of offset is still not appropriately developed in this bill to be an effective and manageable system that supports needed energy and industrial development.

Impact of Uncertainty

Because of these uncertainties, we question whether many of the questions contained in the letter of invitation can be addressed with reasonable accuracy. If in the future it is determined that limits on greenhouse gas emissions are justified and an appropriate level of emission reductions is scientifically established, an emissions trading system, either internationally or nationally, may present the best mechanism for achieving such

reductions at lower aggregate costs to society. However, such a system must be carefully designed to achieve predictability. While we do not believe that steps beyond the NES actions are appropriate, we also do not believe that H.R. 5966 provides the needed predictability if it is subsequently determined that additional steps are needed. Further, the complexity of calculating and initially assigning CO2 and other greenhouse gas offsets as envisioned in the bill is too great to predict the mechanics of the offset bank over the operating life of a new major utility or industrial facility.

We will submit for the record some preliminary answers to the more detailed questions relating to H.R. 5966 posed in your letter to Secretary Watkins. In many cases, the answer depends on elements of the program that cannot be determined. However, in other cases, qualitative answers can be provided. Our analysis to date suggest sizeable negative economic outcomes due to the bill's provisions. For these reasons, we oppose enactment of H.R. 5966. However, it is a useful concept for study. If in later years, we determine control steps beyond existing regulatory mechanisms and the current NES actions are needed to reduce greenhouse gas emissions, an improved emissions trading program could be evaluated along with other added greenhouse gas emissions control proposals.

Conclusion

The National Energy Strategy will contribute substantially to our Nation's energy and economic security, while significantly enhancing the quality of our environment. The benefits underscore the importance of prompt implementation of the NES. When the President directed the Secretary of Energy to lead the development of a National Energy Strategy, he asked for a strategy that balances environmental protection, economic strength and energy security. He also directed that the strategy rely on market mechanisms for flexibility and lower cost. In a similar way, the world community, through the IPCC, has recommended that actions be taken to address greenhouse gases that serve multiple purposes, allowing for the flexibility to go further if the scientific evidence warrants.

The President's Climate Change Action Plan and the National Energy Strategy offer a balanced set of policies that will sustain economic growth, stimulate technological innovation, and improve environmental quality, while addressing effectively the potential for global climate change. We expect that the approach taken in the National Energy Strategy will be a model for other countries, and that it could lead to greater international cooperation to enhance energy security, economic efficiency and environmental quality. We hope to work closely with this Sub-committee as we proceed with implementation of the Climate Change Action Plan and the National Energy Strategy.

Fact Sheet 1
The NAS and NES Emission Intensity Trends

There are two conclusions of the NAS report that some observers have suggested are quite different from Administration positions. But even in these cases, I believe that the differences are more apparent than real.

- The first of these conclusions is that "analysis suggests that the United States could reduce its greenhouse gas emissions by between 10 and 40 percent of the 1990 level at very low costs."

- The second is that the panel members "reached the collective judgement that the United States should undertake several actions that satisfy multiple goals but also several whose costs are justified mainly by countering or adapting to greenhouse warming".

In regard to these conclusions, it is important to keep in mind that the NAS panel analysis is a static analysis; it assumes that 1990 economic and energy levels and patterns are maintained--except for the initiatives proposed by the panel. For example, the panel used the statistics on demands for goods and processes that use chlorofluorocarbons (CFC) now but made chemical substitutes to match the changes that the amended Montreal Protocol would require in year 2000 (that is, full phaseout of many of these compounds). Thus, the NAS analysis required only that the 1990 demand for these goods and services be met--but not the much higher demand that would occur in year 2000.

The National Energy Strategy takes account of economic growth and sectoral changes that are expected to occur.

In one sense, what the NAS panel has said is that the present intensity of greenhouse gas generation in the United States could be cut 10 to 40 percent. This intensity could be measured by comparing greenhouse gas emission levels to a measure of economic activity, such as GNP, or a resource use measure, such as annual primary use of energy.

If we allow for the time needed to effect the proposed economic growth and changes, as is done in our analysis of National Energy Strategy actions, the two reports would have similar results in terms of the intensity of emissions by year 2000 or 2010. Consider this chart, which expresses the emissions reductions in terms of both GNP and energy use.

NAS Report-	1990:	GHG emissions/unit of GNP or GHG/unit of energy reduced 10-40%
NES Actions-	2000:	GHG/GNP cut 32%, GHG/energy cut 21%
	- 2010:	GHG/GNP cut 45%, GHG/energy cut 26%

Thus, if we allow a reasonable time for the economic and other actions leading to emissions reductions to take effect, we find that the NES actions would result in changes that fit comfortably within the NAS panel's range of greenhouse gas reductions compared to current patterns.

Concerning the second element of apparent difference, that some actions of low cost should be taken now, our comparison of the panel's energy policy recommendations in chapter 9 to the Administration's Action Plan and the National Energy Strategy suggests that both have comparable actions although the proposed implementation mechanism is not always the same (see Appendix B).

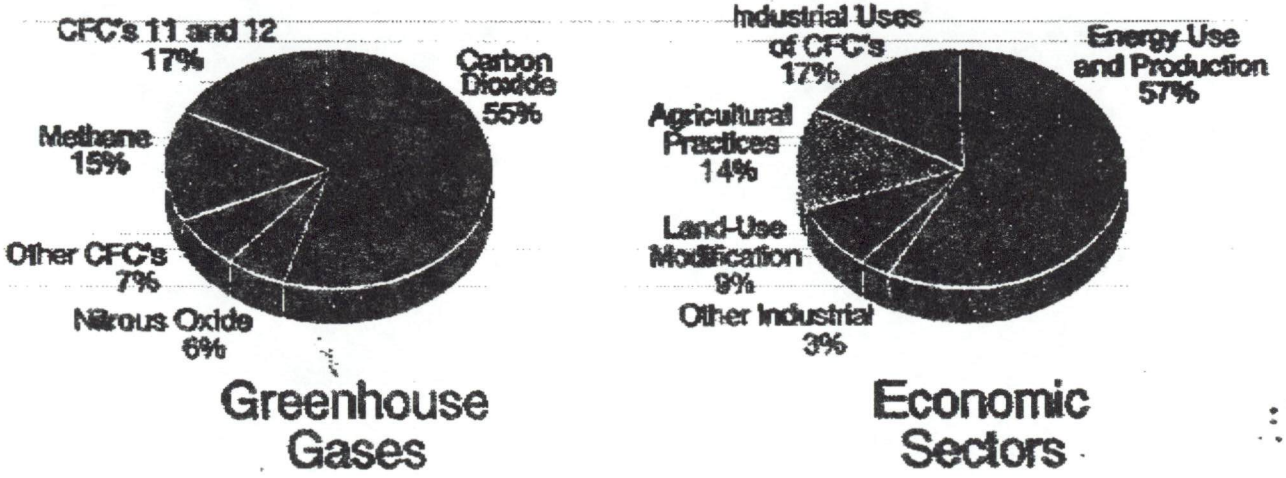
- For example, NAS would propose national building standards while the National Energy Strategy calls for Federal demonstrations of building efficiency improvements, technical assistance to States and local governments to assist them to implement strengthened building standards, and setting cost effective efficiency standards for Federally subsidized buildings.

- In some cases, for example, the phaseout of the CFCs, Federal programs are being implemented that would meet the NAS recommendation.

In nearly all of these actions there are some costs involved. The NAS panel states that we should incur these costs to offset global climate change impacts. In the analogous NES actions, we found that there were ample justification on a cost-benefit basis to take the action for other policy reasons, yet it also benefits our global climate change policy. Is the cost due to global climate change concerns or not?--I believe we are seeing a reflection of the study perspectives of two groups, but not a difference in how the general economy will be affected or in the types of actions that should be undertaken.

Figure 1

Radiative Forcing from Greenhouse Gases
Relative Contributions in 1980's



Note: The contribution from tropospheric ozone may also be significant, but cannot be quantified at present.

Sources: Gases: IPCC Scientific Assessment;
Sectors: EPA, Policy Options for Stabilizing Global Climate,
draft report to Congress, 1990.

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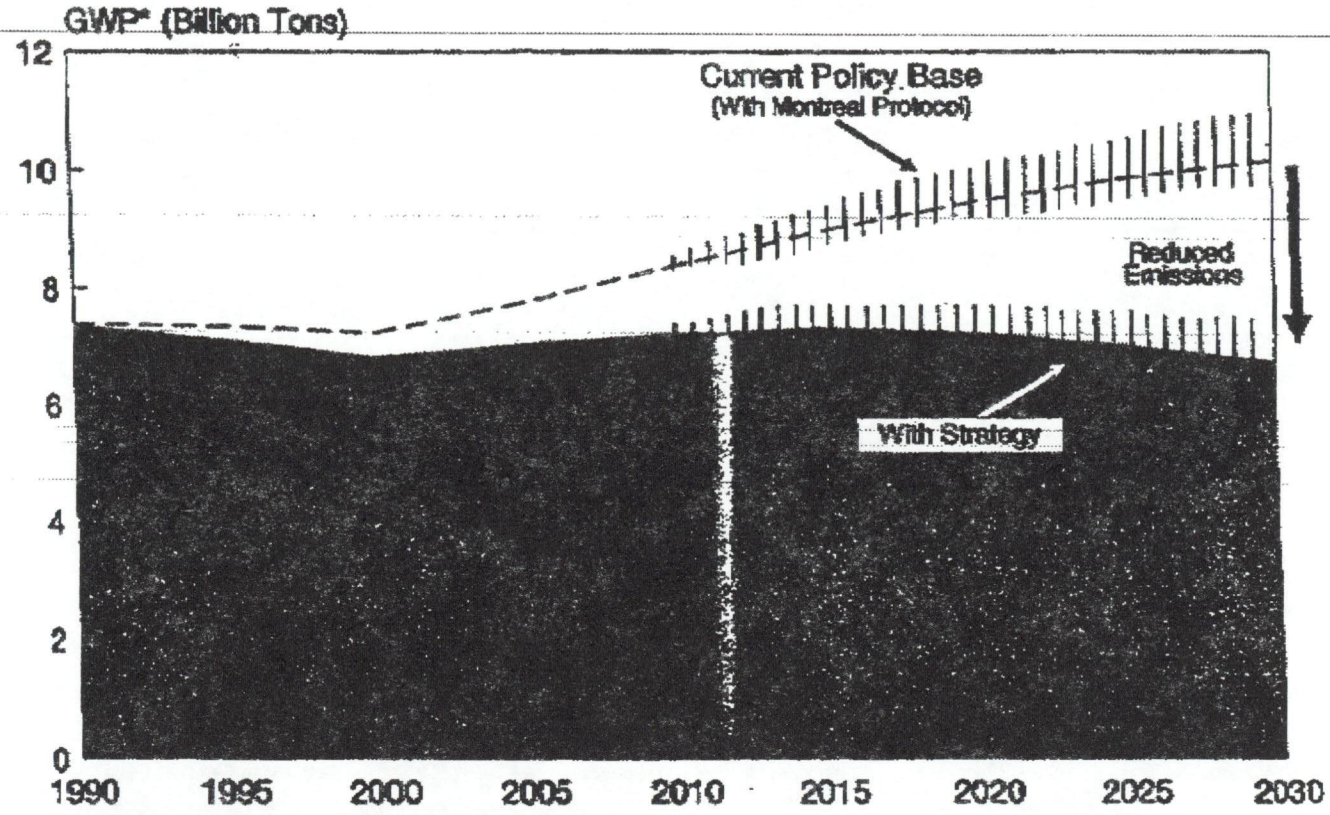
Figure 2

Reduced Potential for Global Warming



*Global warming potential(GWP)- Unit of 100-year global warming potential measured in billion metric tons CO2 equivalents. Greenhouse gases vary in lifetimes and ability to absorb and radiate heat, therefore a common unit is used.

Figure 7 in the National Energy Strategy.

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MITIGATION OPTIONS CONSIDERED BY NAS AND RELATED NES ACTIONS

NAS OPTIONS	NES ACTIONS	NES REPORT-PAGE
Residential and Commercial		
o plant vegetation at homes, white roofs	landscaping and site design	N-45
o replace incandescent lights with compact flourescents	added R&D	N-35,127
	labelling and standards	N-47,53
	integrated resource planning (IRP)	N-35
o water heating	added R&D	N-44
	appliance efficiency labelling and standards	N-47
o commercial cooking, cooling, refrigeration	added R&D	N-52
	information and technical assistance	N-53
	- testing and labelling	
	IRP	N-36
o residential appliances	added R&D	N-44
	appliance efficiency labelling and standards	N-47
	IRP	N-36
o space heating - including ventilation	IRP	N-36
	appliance labelling and standards	N-47,53
	added R&D	N-44,52
	technical information and assistance	N-46,53

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Residential and Commercial (cont'd)

	R&D for building design	N-128
	promulgate building standards	
	- federal and subsidized buildings	N-46,53
	- assist State and local building codes	N-46,53
	develop shell efficiency labels	N-46
o oil and gas heating efficiency	appliance efficiency labelling and standards	N-47,53
	added R&D	N-52
	information and technical assistance	N-53
o fuel switching	information and technical assistance	N-53
	R&D on district heating, co-generation	N-52
	Natural gas regulation reform	N-91

Industrial

o cogeneration replacement system	advanced cogeneration R&D	N-57
	heat recovery R&D	N-59
	energy audits	N-58
o more efficient motors and drives, lighting, process modifications	testing and labelling	N-57
	heat recovery R&D	N-59
	energy audits	N-58
	R&D on industrial processes	N-57
	R&D tax credit	N-58
	use of fuels as feedstocks	N-59
o fuel efficiency	energy audits	N-58
	heat recovery R&D	N-57
	R&D on industrial processes	N-57

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Industrial (cont'd)

o	fuel switching	Natural gas regulatory reform	
o	new process technology	R&D industrial processes	N-57
		R&D tax credit	N-58

Transportation

o	light vehicle fuel economy improvements	incentives to scrap older vehicles	N-65
	heavy vehicle fuel economy improvements	determine feasible cost-effective fuel economy levels	N-65
		improve customer information on efficiency and maintenance	N-67
		improved propulsion R&D	N-66
o	aircraft technologies	improved air traffic control systems	N-72
		magnetic levitation	N-72
o	alternative fuels - methanol - electricity from nuclear and renewable sources	R&D programs	N-67
		incentives for alternative fuel vehicles	N-68
		federal alternative vehicle fleet	N-68
		public alternative vehicle fleets	N-68
		ethanol tax credits	N-69
		advanced fuels from biomass	N-69
		public education, technology transfer	N-71
o	transportation demand management	mass transit/ridesharing	N-72
		highway flow management	N-72
		telecommuting	N-72

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Electricity and Fuel Supply

o	heat rate improvements	more efficient repowering technologies	N-114
		facilitate powerplant refurbishment	N-103
o	advanced technologies	clean coal technology	N-100,103
	- coal	advanced R&D	
	- natural gas	advanced R&D	N-87
	- nuclear	new standard plants design	N-111
		improved licensing	N-113
	- hydroelectric	hydroefficiency R&D	N-123
		~~improved regulatory processes~~	~~N-123~~
		environmental research	N-123
	- biomass	advanced R&D	N-124
	- photovoltaic, solar, wind	information and technical assistance	
		increased R&D	N-124
		investment tax credit	N-124
		PURPA reform	N-125
	- CO2 disposal	R&D on CO2 sequestering	N-104

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Appendix B

Comparison of NAS Panel Recommendations on Energy Policy and the National Energy Strategy

The Panel recommended that the "full social cost pricing" of energy be studied in detail, with a goal of gradually introducing such a system.

The National Energy Strategy recognizes that "the goals of a healthy environment and reduced dependence on insecure suppliers represent national security, foreign policy, and social benefits to which private markets are unlikely to give adequate weight." There are a number of ways in which externalities can be introduced into the price of energy. For example, the tradeable allowances for sulfur dioxide emissions from power plants enacted in the Clean Air Act Amendments represent a major step in incorporating environmental values into electricity pricing.

As part of the National Energy Strategy implementation, the Administration has launched a joint, international study of fuel cycle costs with the European Commission and Japan. The purpose of this joint study is to develop an international consensus on a scientific methodology to assess the full costs of fuel cycles.

The Panel recommended that nationwide energy-efficient building codes be adopted.

The National Energy Strategy (NES) proposes technical and financial support for the development of efficiency guidelines and model building codes, although it leaves decisions to the states and localities. In addition, all new Federal buildings will continue to be required to meet stringent efficiency standards and buildings subsidized by federal funds or federally insured mortgages will be required to equally stringent meet energy efficiency standards. In order to encourage further increases in building energy efficiency, the NES also supports the widespread use of home energy ratings and energy efficient mortgages for both new and existing housing.

The Panel recommended that the efficiency of the U.S. automotive fleet be improved through a combination of regulation and tax incentives. The Panel prefers modest CAFE standards (32 MPG, date uncertain) to very extreme CAFE standards (46 MPG).

The NES analysis concluded that auto fuel economy was likely to increase to more than 32 mpg by the year 2000, even without the imposition of new standards. Higher standards might result in further increases in fuel economy, but such standards might conflict with the achievement of other environmental, safety and economic objectives. In order to examine these potential conflicts more carefully, the NES called for the completion of a study of these issues that had already been commissioned by the Department of Transportation and is due to be completed this summer. The NES also examined the likely impacts of various regulatory and tax incentives, but concluded that all would entail significant economic costs. The NES did propose, however, to expand significantly Federal support of more energy efficient transportation technologies and to encourage State and local governments to undertake programs to accelerate the scrapping of older, less efficient and heavily polluting cars.

The Panel recommended that Federal and State support of mass transit be strengthened.

The NES proposes to increase the amount of tax-free transit benefits that employers may provide to employees. It also supports carpooling, HOV rights-or-way, improved public transportation services, initiatives in magnetic levitation for intercity rail, improved air traffic control, and telecommuting.

The Panel recommended that appliance efficiency standards be improved.

The NES calls for continued updating of appliance standards under existing authority. Under NES, the Administration is also seeking authority to extend testing and labeling programs to certain nonresidential equipment, including lighting and controls, office equipment, and electric motors. Finally, appliance efficiency will be promoted through Integrated Resource Planning efforts by utilities, as described below.

The Panel recommended that public education and information programs for conservation and recycling be encouraged (though it did not call for recycling mandates).

The Administration is very active in promoting conservation and

recycling. The NES emphasizes waste minimization, and both the Department of Energy and the Bureau of Mines have active research programs addressing waste elimination or minimization through recovery of a wide range of economically attractive but toxic materials from industrial waste streams.

The EPA has initiated the "Green Lights" program to encourage improved lighting by major corporations. Under Administrator Reilly, the EPA has also pushed pollution prevention more generally, including issuing a pollution prevention strategy in January 1991.

The Panel recommended that State public utility regulation be reformed to encourage utility promotion of efficiency and conservation.

The NES proposes to foster Integrated Resource Planning (IRP) by providing states and utilities with financial assistance, technical data, and evaluation criteria. In addition, federal power marketing administrations will intensify their efforts to promote IRP. Federal loan subsidies to power marketing administrations that discourage conservation by artificially lowering power prices will be phased out over a 10-year period.

FERC will be encouraged by the Department of Energy to exercise its authority over wholesale power transactions in a manner that promotes IRP. And the Internal Revenue Service will issue a ruling clarifying that price reductions or nonrefundable credits on utility bills provided by utilities to encourage conservation are not taxable income.

The Panel recommended sharply increasing the emphasis on efficiency and conservation in the federal energy R&D budget.

The fiscal year 1992 budget proposes a 22 percent increase in research and development on energy efficient buildings and industry, a 60 percent increase in research and development for surface transportation efficiency, and a 16 percent increase in air transportation efficiency. With these increases, Federal funding of conservation R&D will have increased by more than 80% since 1989.

The Panel recommended that federal and state purchases of goods be used to demonstrate best-practice technologies and energy conservation programs.

The President's Executive Order on Federal Energy Management requires Federal agencies to incorporate life-cycle costing methods into their procurement decisions to assure the purchase of the most cost-effective, efficient products. This could spur the development of a new generation of energy-efficient products by private industry.

In addition, the Administration has moved the Federal government to the forefront of efforts at more efficient use of energy. In April, the President issued an Executive Order directing all Federal agencies to reduce by 20 percent the energy used in Federal buildings and industrial facilities by the year 2000, compared to 1985 levels, and to reduce fuel consumption in Federal vehicles by 10% by 1995 from current levels.

The NES also directs DOE and HUD to expand their efforts to improve the energy efficiency and management of Federally-supported public housing.

<u>The Panel recommended that combined cycle systems be developed that have efficiencies approaching 60 percent of both coal- and natural-gas-fired plants.</u>

Power plants with such high levels of performance are not ready to begin commercial deployment at this time. For this reason, the Department is aggressively pursing research and development on a series of progressively more efficient fossil-fired systems. For example, fuel cell technology will evolve from phosphoric acid cells, with 40-50% efficiency; to molten carbonate fuel cells, with 45-60% efficiency; to solid oxide fuel cells, with 50-60% efficiency. This is a major improvement over today's pulverized coal plants which are only 33% efficient. With respect to timing, we intend to demonstrate molten carbonate and solid oxide cells fueled by natural gas by 1998, with commercial deployment shortly thereafter. Coal based systems will lag the development of gas systems, but even solid oxide coal-fuel cells are expected to be commercially deployed by 2025.

<u>The Panel recommended that broader use of natural gas be encouraged by identifying and removing obstacles in the distribution system.</u>

The NES proposes to (1) clarify the right to build pipelines without a certificate of public convenience and necessity as allowed under the NGPA of 1978; (2) expedite FERC action on natural gas pipeline projects; (3) expedite the environmental review process for natural gas pipeline projects; (4) increase third-party access to nondiscriminatory transportation by

pipelines; (5) unbundle pipeline pricing; (6) use economically efficient rate designs, including seasonal rates; (7) deregulate rates for new pipelines; (8) eliminate unnecessary regulation of exports and imports; and (9) study state regulatory practices affecting the production and use of natural gas.

The Panel recommended that a new generation of nuclear reactor technology be developed and tested operationally that is designed to deal with safety, waste management, and public acceptability.

In addition to pursuing the development of ALWR (with the goal of having the first plant operational before the year 2000), the Department of Energy will continue to support the ALMR and the modular High Temperature Gas Reactor(HTGR) designs. The latter designs may offer significant safety and waste management advantages as well as higher efficiencies and production of industrial process heat in addition to their electrical output.

Regarding nuclear waste, the permanent repository and monitored retrievable storage (MRS) sites for waste storage should be identified for use beginning in 2010 and 1998, respectively. The DOE is planning to develop these facilities in these timeframes, given enactment of NES legislation, and increase its participation in nuclear waste management decisions.

The Panel recommended that R&D on alternative energy supply technologies be increased, and that energy systems be designed using them in conjunction with other energy supply technologies.

The F budget reflects research priorities i e
direc including a strong effort in biomass e
exper f renewable research efforts through c ared
coll. ve ventures. Federal funding of rene energy R&D

Greenhouse files

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FAX 17 pgs

URGENT

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF MANAGEMENT AND BUDGET
Washington, D.C. 20503

JUN 14 1991

LEGISLATIVE REFERRAL MEMORANDUM

LRM #I-826

TO: Legislative Liaison Officer -

AGRIC-CR - Cindy Ayers (all testimony) - 447-9201 - 230
COMMERCE - Michael A. Levitt - 377-3151 - 324
DEFENSE - Samuel T. Brick, Jr. - 697-1305 - 325
INTERIOR - Pam Somers - 208-6706 - 329
JUSTICE - Paul McNulty - 514-2061 - 217
STATE - Will Davis - 647-4463 - 225
TRANSPORTATION - Tom Herlihy - 366-4687 - 226
CEA - Francine Obermiller - 395-5036 - 242
CEQ - Larry Flick - 395-5750 - 256
ENERGY - Bob Rabben - 586-6718 - 209
NASA - Martin P. Kress - 453-1948 - 219
NSF - Charles H. Herz - 357-9435 - 248
OSTP - Damar Hawkins - 456-6272 - 288

SUBJECT: EPA Proposed Testimony RE: HR 1301, "National Energy Strategy Act"

This testimony deals with the effect of the National Energy Strategy on Greenhouse Gas Emissions

DEADLINE: COB Today **JUN 17 1991**

The Office of Management and Budget requests the views of your agency on the above subject before advising on its relationship to the program of the President, in accordance with OMB Circular A-19.

Please advise us if this item will affect direct spending or receipts for purposes of the "Pay-As-You-Go" provisions of Title XIII of the Omnibus Budget Reconciliation Act of 1990.

Questions should be referred to **Holly FITTER (395-6194)**, the legislative analyst/attorney in this office or to **Norman HARTNESS (395-6840)**.

You may respond to this request for views by: (1) faxing us the attached response sheet; (2) if the response is simple (e.g., concur/no comment), leaving a message with the secretary of the above-named analyst/attorney; (3) calling the analyst/attorney; or (4) sending us a memo or letter.

Ronald K. Peterson

RONALD K. PETERSON for
Assistant Director for
Legislative Reference

CC:
M. Buegg
J. Fellows
E. Watts
A. Fraas
T. Gorman
H. Williamson
C. G. Gray/J. Holmstead

LRM #I-826

RESPONSE TO LEGISLATIVE REFERRAL MEMORANDUM

TO: Holly FITTER
Office of Management and Budget
Fax Number: 395-5691
Phone Number: 395-6194

_____ (Date)

FROM: _____ (Name)

_____ (Agency)

_____ (Telephone)

SUBJECT: EPA Proposed Testimony RE: HR 1301, "National Energy Strategy Act"

The following is the response of our agency to your request for views on the above-captioned subject:

_____ Concur

_____ No objection

_____ No comment

_____ See proposed edits on pages _____

_____ Other: _____

TESTIMONY OF

DR. RICHARD D. MORGENSTERN
ACTING ASSISTANT ADMINISTRATOR
FOR POLICY, PLANNING AND EVALUATION
U.S. ENVIRONMENTAL PROTECTION AGENCY

BEFORE THE
SUBCOMMITTEE ON ENERGY AND POWER
U.S. HOUSE OF REPRESENTATIVES

JUNE 19, 1991

Good morning. I am Richard D. Morgenstern, Director of the Office of Policy Analysis, and Acting Assistant Administrator of Policy, Planning and Evaluation at the U.S. Environmental Protection Agency (EPA). I am pleased to be here today to discuss energy policy initiatives and climate change.

Today, I will do three things. First I will begin discuss how climate change might be addressed in the context of energy legislation. Secondly, I will review specific measures and components included in pending legislation. Finally, I will discuss "The Greenhouse Warming Response Resolution of 1991" and the Cooper-Synar emissions trading legislation.

Energy Policy vis-a-vis the Potential For Climate Change

Energy policy is currently incorporated into the U.S. comprehensive approach to climate change — an approach which addresses multiple aspects of the problem. The

U.S. strategy is built upon a policy of "no regrets" — this involves a series of actions which will have broad ranging benefits — from curbing air pollution, to conserving energy, to restoring forest lands — and which will also help curb net greenhouse gas emissions. Any successful global climate change strategy — and its energy policy component — must be comprehensive and long term in its perspective, flexible in its design, and integrated so as to involve all nations and incorporate each nation's unique circumstances into the development of a global response strategy.

Flexibility is important when designing policies. We believe that a modular approach consisting of a set of specific actions with multiple benefits will provide the needed flexibility to quickly and intelligently adjust U.S. response strategy as knowledge regarding climate change is expanded, and as more is learned about the effectiveness of each component action.

A number of U.S. actions were described in the publication *America's Climate Change Strategy: An Action Agenda* — a realistic approach to climate change that provides the essence of an "insurance policy" by delaying possible climate change while our understanding of the phenomena involved develops further and we continue to develop appropriate technologies, and behavioral, organizational, and market response strategies. When analyzed using the IPCC global warming potential values which allow a comprehensive comparison of greenhouse gases, these actions will result in U.S. greenhouse gas emissions in the year 2000 being equal to or below the 1987 level. Since the publication of the *Action Agenda*, decisions have been made to take additional actions as a part of the National Energy Strategy (NES). Realization of both sets of

actions will substantially curb the growth of greenhouse gases below projected levels beyond the year 2000 and will allow us to hold emission levels within a range that is close to current levels well into the foreseeable future.

In addition, the strategy includes the world's largest program of research and development (1) aimed at increasing our understanding of climate change and other global changes — through the U.S. Global Change Research Program; and, (2) directed towards developing energy efficient technologies — both supply-side and end-use technologies — that are economically sound and environmentally beneficial. The proposed funding for these efforts in FY 1992 is more than $2 billion.

EPA plays an important and significant role in both the scientific and economic research programs. EPA's current scientific research program will reduce uncertainties by increasing our understanding of the carbon cycle, sources, sinks, and feedbacks, and will enable us to better predict the impacts of global climate change. The program will provide methane emissions estimates and control technologies for major sources, quantification of anthropogenic emissions and natural terrestrial fluxes for the U.S.* In addition, the program will provide quantification of terrestrial response, vegetation redistribution, and biogenic emissions from deforestation and biomass burning, as well a

* EPA is also preparing a set of Reports to Congress on opportunities for reducing methane emissions in the U.S. and world-wide. These reports will discuss available technologies for reducing methane emissions from sources such as coal mining, landfills, and natural gas systems. The reports will identify existing barriers to the profitable reduction of these emissions and recommend changes to policies and practices to remove these barriers. One example is the property rights issue in the Appalachian region of the U.S. which is hindering the profitable development of coalbed methane resources and is promoting the venting of this useful gas, as opposed to its recovery.

provide a preliminary understanding of the potential for carbon sequestration by forest and agricultural management in the U.S.

EPA's economic analyses focus on options to mitigate greenhouse gas emissions both domestically and internationally. Our efforts range from examining the effectiveness of incentive programs such as carbon fees and emissions trading, to policies designed to simulate the commercialization of fuels and technologies which emit less greenhouse gases. We are also examining potential regulatory and market reforms which could stimulate greater efficiency and reduced pollution.

Legislative Measures

As discussed above, a prudent balancing of specific actions with broad-ranging benefits, including the use of appropriate incentive mechanisms, will provide us with a strategy that suitably responds to the risks of climate change. Energy sector initiatives will be important to climate change mitigation strategies both because of energy's large proportional contribution and the many low cost mitigation options available in the energy sector. The NES recognized the link between energy consumption and the production of environmental externalities, highlighting several key ways in which to enhance environmental protection, including the mitigation of emissions of greenhouse gases, while meeting the U.S. goals of increased energy security and economic growth.

EPA has long recognized the critical link between environmental and energy issues, and we are aggressively pursuing this relationship in a variety of analytic efforts. In your letter of invitation you asked for a relative ranking of greenhouse gas mitigation

options. While EPA has not conducted a fully integrated analysis of all options, we have conducted analysis of specific classes of options. Our analytic efforts are focused on the macroeconomic effects of alternative energy policy options, transportation--and utility-sector-specific studies, and international trade impacts of greenhouse gas mitigation regimes.

In regards to transportation-sector policy alternatives, an analysis conducted for EPA indicates that the maximum technical potential for automobile efficiency without a shift in the relative mix of automobile size and performance is 38.2 miles per gallon (mpg) in the year 2001; the fuel economy standards of 32.6 to 35.5 mpg would pay for themselves assuming a four year and ten year payback, respectively.* Assuming that the Bryan bill target of 40.2 mpg is achieved through some combination of size and performance shifting, EPA analysis indicates savings of 795,000 barrels of oil per day, accounting for changes in consumer and manufacturers behavior that would otherwise occur. This is equal to approximately 120 million tons of CO_2 per year (33 million tons of carbon), or approximately 2.5% of current U.S. CO_2 emissions (1.4% of total greenhouse gas emissions).

In an analysis of several transportation-sector options, including alternative fuels, to reduce greenhouse gases, a recent draft report produced for EPA concludes that "the greatest greenhouse benefits over the base case gasoline scenario comes from improving gasoline vehicle efficiency, followed by using CNG, and then methanol; using

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* Duleep, K.G., Energy and Environmental Analysis, Inc., *An Assessment of Potential Passenger Car Fuel Economy Objectives For 2010*, February 1991.

reformulated gasoline increases greenhouse gas emissions."* The report represents an up-to-date and thorough summary of existing alternative fuels studies using a consistent set of assumptions and methodological framework to rerun existing alternative fuels models, demonstrating a consistency of results.

Although not included in the above ranking, a report by Abt & Associates concludes that ethanol use could reduce automobile-sector greenhouse gas emissions (on a CO_2-equivalent basis) by 48% after accounting for emissions from fuel production as well as consumption."**

In the area of electric and gas utilities and building energy consumption, any effective mitigation strategy will necessarily depend on the development and use of low- or non-CO_2-emitting energy resources. Demand-side policies which encourage the substitution of more energy-efficient end-use capital for purchases of fossil fuels used for electricity generation and the direct combustion of natural gas in end-use equipment offer great potential to provide such a "zero-emissions" resource. Policies which encourage economic pricing of energy inputs and abolition of uneconomic subsidies or purchasing preferences will also help promote a substitution towards more energy-efficient end-use equipment. The NES would encourage utilities to consider investing in end-use efficiency rather than new power production, using Integrated Resource Planning (IRP) and promoting the growth of independent, competitive energy service companies. In the area of commercial and residential energy use, the NES recognized that DOE

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* Walls, Margaret, et. al., Draft *Greenhouse Gas Emissions From Alternative Fuels*, April 1991.

** McGartland, Albert, et. al., Draft *A Methodology for Evaluating the Costs and Global Warming Implications of Ethanol*, April 1991.

efficiency labelling programs will help both commercial and residential lighting and appliance buyers choose the efficiency technology that is right for them. A similar policy will encourage home mortgage lenders to share energy efficiency rating with prospective home buyers.

Other actions currently being undertaken include EPA's GREEN LIGHTS program. GREEN LIGHTS is a voluntary, non-regulatory program sponsored by EPA which encourages major U.S. corporations to install energy-efficient lighting technologies. Green Lights is based on a pollution prevention strategy and is designed to accelerate the adoption of current energy efficient technologies. Corporations become GREEN LIGHTS *Partners* by agreeing to undertake certain specific actions, including: (1) surveying the lighting in all of its U.S. facilities and considering a range of individual energy efficient lighting technologies and packages; (2) retrofitting 90% of its square footage with energy efficient lighting packages that maximize energy savings, so long as they are profitable and do not compromise lighting quality; and, (3) agreeing to retrofit its facilities within 5 years, and agreeing to re-survey and re-analyze profitable lighting option no later than five years after completing the retrofits. In return, EPA agrees to provide several types of program support, including technical and informational support.

The early success of the GREEN LIGHTS program has encouraged the EPA to explore other options for voluntary, non-regulatory pollution prevention strategies. Current plans are to launch a second program when GREEN LIGHTS has grown to 500 participating corporations. Additional programs would focus on specific institutional or

corporate settings which show promise for energy efficiency gains and which are likely lend themselves to programmatic approaches.

On the supply-side, PURPA (Public Utility Regulatory Policies Act) reform would encourage renewable energy production by expanding market access for cogeneration and renewable energy sources. Nuclear and hydro licensing reform could expand the use of these two non-emitting resources. The NES proposes natural gas pipeline regulatory reform that will lower natural gas prices and encourage its expanded use -- thereby lowering emissions to the extent that it is used for power generation, and increasing efficiency to the extent that it is used directly in many end-use applications. Likewise, natural gas import and export deregulation should lead to increased gas use both here and abroad. Overall, the NES stresses the importance of continued federal R&D funding to enhance the development of more energy-efficient technologies -- both supply- and demand-side.

In the area of transportation, alternative fuels requirements for fleets will help further the alternative fuels provisions of the Clean Air Act to reduce ozone and carbon monoxide emissions in our cities, and decrease dependence on oil. However, the impact of these provisions on greenhouse gas emissions will likely be small or negligible. Also, outreach and technical assistance will help states, cities, and private industry to initiate accelerated scrappage programs to remove old, high-polluting and gas-guzzling cars from the road. Finally, a change in the tax code will allow employers to increase the tax-free subsidies they give their employees for riding public transit, vanpooling, and ridesharing.

In addition to the near-term response strategies outlined above, EPA and other executive agencies, such as DOE and DOC, are examining the effectiveness and possible economic effects of various longer-term response strategies involving mitigation and adaptation. Most of the current studies consider only CO_2 emissions on a gross emissions basis (e.g., energy- and industry-related direct emissions as opposed to net emissions which would account for emission sinks as well). Among the studies sponsored by EPA is one using Jorgenson and Wilcoxen's 35 sector econometric model of the U.S. economy. Preliminary results of a carbon tax analysis indicate that emissions can be maintained at 1990 levels through the imposition of a phased carbon tax that rises to a level of approximately $17 per ton in 2020, with a resulting average percentage loss in real GNP of 0.5%.

Studies which have shown larger GNP effects have typically examined energy taxes that reduce investment and consumer purchasing power without implementing any offsetting tax policies. An EPA-sponsored DRI/McGraw Hill analysis shows that targeting the recycling of tax revenues can reduce and potentially eliminate adverse GNP effects. This study analyzed the differential macroeconomic impacts of a gasoline tax sufficient to maintain light duty vehicle carbon emissions at 1989 levels through 2010. In one scenario analyzed, the gasoline tax revenues were accompanied by a reduction in personal income taxes, resulting in a GNP loss of 0.4% in the year 2000. In another scenario, the gasoline tax revenues were accompanied by a reduction in payroll taxes (paid by businesses), thereby lowering unit labor costs and prices of various goods and services. The result of this type of offsetting tax reduction is that GNP is projected to be

virtually unchanged from baseline levels. This analysis highlights the need for a thorough economy-wide analysis of the full costs and effects of any mitigation strategy.

The Greenhouse Warming Response Resolution of 1991

The National Academy of Sciences' *Policy Implications of Greenhouse Warming* is a thorough and clear exposition of a complex issue; it is a consensus document which provides a valuable synthesis of policy insights and approaches from various scientific and professional disciplines. The report provides a well-documented discussion of the science of climate change, as well as a discussion of the nature and extent of the uncertainties. Notwithstanding these uncertainties, the report recommends a set of specific, proactive steps that can be prudently taken now. Some of the recommendations made in the report are very similar to actions that have been taken or have been proposed by the Administration in the NES, *America's Climate Change Strategy: An Action Agenda*, the Clean Air Act Amendments of 1990, and in other policy documents. The Academy's report's finding that a 10% to 40% reduction in greenhouse gas emissions could be achieved at low cost assumes a constant 1990 level of economic activity. If the Administration's policies were converted to such a static scenario (or "cross-sectional" analysis, as it is denoted in the Academy's report), these policies would yield greenhouse emissions reductions comfortably within the range advocated by the Academy.

One tool highlighted by the Academy's report is the call for the detailed study of the "full social cost pricing" of energy. Although environmental and social controls

currently exist, it is doubtful that all external costs are fully incorporated at the present time. The EPA is studying this issue and we hope to be able to report on our results later this year.

Cooper-Synar Emissions Trading Proposal

The Cooper-Synar proposal offers an administrative program to control greenhouse gases which incorporates a market-based incentive scheme.* Although such a unilateral approach reflected in Cooper-Synar must be opposed because of the competitive disadvantage that it will impose on the U.S. as well as because of the need to formulate a greenhouse gas response strategy in a multilateral framework, the proposal deserves praise for its creative use of market forces and its comprehensive nature — i.e., including several different greenhouse gases and including both sources and sinks.

Cooper-Synar caps CO_2 emissions from large industrial and utility sources. The proposed legislation requires that new large industrial and utility sources obtain "CO_2 credits" in order to operate. These CO_2 credits will be created by "offsets" or reductions in greenhouse gas emissions below "baseline" levels (or sequestration above baseline levels) from any source as certified by the EPA Administrator. The law then list several specific sources of offsets, although the bill also makes clear that the Administrator should consider other sources of offsets when certifying CO_2 credits.

* As per the invitation letter, my comments are based on the version of Cooper-Synar introduced last year (H.R. 5966 of the 101st Congress).

Emissions trading schemes are favored because they help ensure that any given level of reduction is achieved at minimum costs. Moreover, they provide a continuing incentive to either reduce emissions or lower compliance costs. The Cooper-Synar bill reflects many of the advantages of emissions trading schemes. The creation of the "National CO_2 Offset Bank" allows for free trading of the emission credits, such that emission reductions should be achieved at least cost. The bill also takes an appropriately broad view of measures that can reduce emissions. By offering CO_2 offset credits for numerous activities, including surpassing CAFE standards, surpassing appliance efficiency standards, and reforestation, the bill encourages environmental awareness and action not only among emitters, but among other producers and consumers. By offering offset credits for reductions in other greenhouse gases, including N_2O, methane, and CFCs, in excess of those already required by law, the bill rightfully furthers the view that the level of all greenhouse gas emissions, not just CO_2, should be the object of concern in global climate change policy.

The bill, however, raises numerous questions and concerns that should be considered more fully. A recent scoping study conducted by Decision Focus Incorporated for the EPA provides a thorough discussion of the important issues and considerations that must be addressed when designing an emissions trading scheme.* Among the features unique to a greenhouse gas trading system (contrasted with an SO_2 trading system) is the ubiquity of sources; greenhouse gas emissions come from economic activity as diverse as agriculture, power generation, resource extraction, and

* Smith, Anne; Anders Gjerde; and David Cohan, 1991, *Practical Considerations In Using Emissions Trading To Control Greenhouse Gases.*

transportation. As reflected in Cooper-Synar, options even exist to create sinks (i.e., activities that effectively have negative emissions).

This diversity of possible participants increases the opportunities for trading to minimize control cost expenditures. This diversity also increases the cost associated with monitoring and enforcement. According to the proposed legislation, EPA must monitor and enforce, or design rules to enable state permitting authorities to monitor and enforce, the emission levels and the various offsetting activity levels to determine credits and penalties. For greenhouse gases other than CO_2, many emissions are not at specific point sources such as a stack, and direct monitoring may not be feasible in a way that allows attribution back to an individual producer. Moreover, greenhouse gases other than CO_2 and CFCs lack well-founded historical baselines of emissions. Depending upon the program design, the administrative burden may be overwhelming, with strong incentives for cheating and gaming the system, where environmental gains may appear on paper but not in reality. A workable program may have to be focused on different production or consumption levels for each greenhouse gas, or in some other way account for the uniqueness of the various gases, sources, and sinks.

Other implementation issues associated with Cooper-Synar need to be explored further. The bill focuses on emission of CO_2 from large, new sources, thereby effectively capping emissions from that class of greenhouse gas sources. (Although utilities account for approximately two-thirds of SO_2 emissions, they only account for approximately one-third of CO_2 emissions, or approximately 20% of greenhouse gas emissions.) Other

sources of greenhouse gases (small CO_2 emitters and all other greenhouse gas emitters) may participate by creating offsets, but they are not required to.

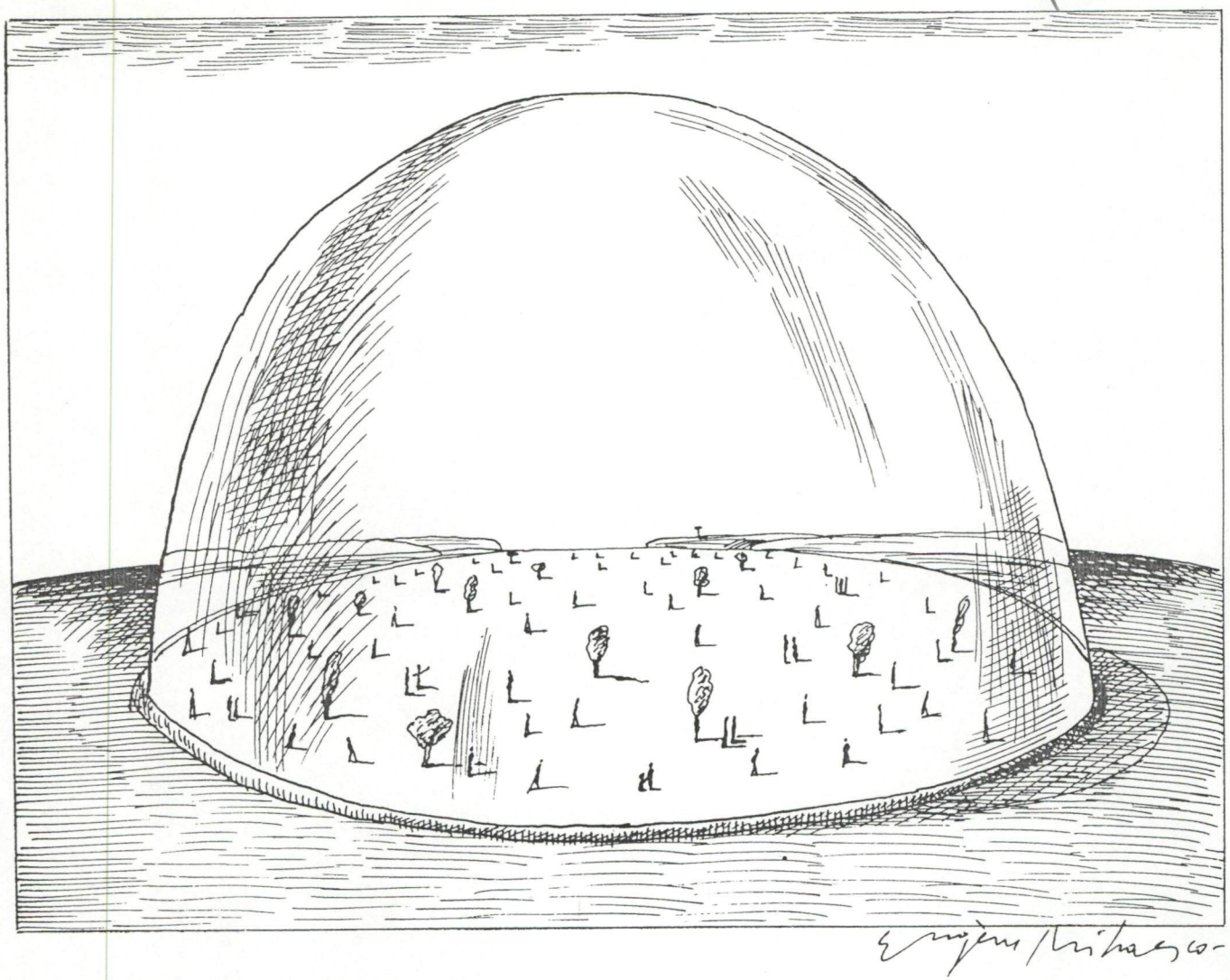
Similarly, the punitive aspects of the bill fall only on new sources. While existing sources can benefit by reducing emission and receiving valuable offset credits, only new sources are bound by the requirement to obtain credits if emissions rise over the threshold. This makes new sources relatively more expensive, and might result in the prolonged use of high-emitting existing sources instead of the creation of new lower-emitting sources. Because capital is very durable and currently no CO_2-removing retrofit (e.g., scrubber) is available, existing sources are likely to remain the majority of industrial and utility capital for many years, delaying the benefits of this scheme. And, because of the higher costs of new sources, the bill may act as a barrier to entry for some industries and utility service areas. A new source that must obtain CO_2 credits might not be able to compete with an existing source, limiting competition and affording existing utilities and firms some monopoly power.

Mr. Chairman, thank you for your invitation to present testimony before the Committee. This has been a welcome opportunity to discuss energy-related climate change issues. I would be pleased to answer any questions you may have.

REFLECTIONS

Greenhouse file

THE END OF NATURE



NATURE, we believe, takes forever. It moves with infinite slowness through the many periods of its history, whose names we can dimly recall from high-school biology—the Cambrian, the Devonian, the Triassic, the Cretaceous, the Pleistocene. At least since Darwin, nature writers have taken pains to stress the incomprehensible length of this path. "So slowly, oh, so slowly, have the great changes been brought about," John Burroughs wrote in 1912. "The Orientals try to get a hint of eternity by saying that when the Himalayas have been ground to powder by allowing a gauze veil to float against them once in a thousand years, eternity will only have just begun. Our mountains have been pulverized by a process almost as slow." We have been told that man's tenure is as a minute to the earth's day, but it is that vast day that has lodged in our minds. The age of the trilobites began six hundred million years ago. The dinosaurs lived for a hundred and fifty million years. Since even a million years is utterly unfathomable, the message is: Nothing happens quickly. Change takes unimaginable—"geologic"—time.

This idea about time is essentially misleading, for the world as we know it, the world with human beings formed into some sort of civilization, is of quite comprehensible duration. People began to collect in a rudimentary society in the north of Mesopotamia some twelve thousand years ago. Using twenty-five years as a generation, that is four hundred and eighty generations ago. Sitting here at my desk, I can think back five generations—I have photographs of four. That is, I can think back one-ninety-sixth of the way to the start of civilization. A skilled genealogist could easily get me one-fiftieth of the distance back. And I can conceive of how most of those forebears lived. From the work of archeologists and from accounts like those in the Bible I have some sense of daily life at least as far back as the time of the Pharaohs, which is almost half the way. Three hundred and twenty generations ago, Jericho was a walled city of three thousand souls. Three hundred and twenty is a large number, but not in the way that six hundred million is a large number, not inscrutably large. And within those twelve thousand years of civilization time is not uniform. The world as we really know it dates back to the Renaissance. The world as we *really* know it dates back to the Industrial Revolution. The world

"And what, pray tell, is the ratio of flake to raisin this morning?"

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as we feel comfortable in it dates back to perhaps 1945.

In other words, our sense of an unlimited future, which is drawn from that apparently bottomless well of the past, is a delusion. True, evolution, grinding on ever so slowly, has taken billions of years to create us from slime, but that does not mean that time always moves so ponderously. Over a lifetime or a decade or a year, big and impersonal and dramatic changes can take place. We have accepted the idea that continents can drift in the course of aeons, or that continents can die in a nuclear second. But normal time seems to us immune from such huge changes. It isn't, though. In the last three decades, for example, the amount of carbon dioxide in the atmosphere has increased more than ten per cent, from about three hundred and fifteen parts per million to about three hundred and fifty parts per million. In the last decade, an immense "hole" in the ozone layer has opened up above the South Pole each fall, and, according to the Worldwatch Institute, the percentage of West German forests damaged by acid rain has risen from less than ten per cent to more than fifty per cent. Last year, for perhaps the first time since that starved Pilgrim winter at Plymouth, America consumed more grain than it grew. Burroughs again: "One summer day, while I was walking along the country road on the farm where I was born, a section of the stone wall opposite me, and not more than three or four yards distant, suddenly fell down. Amid the general stillness and immobility about me, the effect was quite startling. . . . It was the sudden summing-up of half a century or more of atomic changes in the material of the wall. A grain or two of sand yielded to the pressure of long years, and gravity did the rest."

In much the same comforting way that we think of time as imponderably long, we consider the earth to be inconceivably large. Although with the advent of space flight it became fashionable to picture the planet as a small orb of life and light in a dark, cold void, that image never really took hold. To any one of us, the earth is enormous, "infinite to our senses." Or, at least, it is if we think about it in the usual horizontal dimensions. There is a huge distance between my house, in the Adirondack Mountains, and Manhattan—it's a five-hour drive through one state in one country of one continent. But from my house to Allen Hill, near town, is a trip of five and a half miles. By bicycle it takes about twenty minutes, by car seven or eight. I've walked it in an hour and a half. If you turned that trip on its end, the twenty-minute pedal past Bateman's sandpit and the graveyard and the waterfall would take me to the height of Mt. Everest—almost precisely to the point where the air is too thin to breathe without artificial assistance. Into that tight space, and the layer of ozone above it, are crammed all that is life and all that maintains life.

This, I realize, is a far from novel observation. I repeat it only to make the case I made with regard to time. The world is not as large as we intuitively believe—space can be as short as time. For instance, the average American car driven the average American distance—ten thousand miles—in an average American year releases its own weight in carbon into the atmosphere. Imagine every car on a busy freeway pumping a ton of carbon into the atmosphere, and the sky seems less infinitely blue.

Along with our optimistic perceptions of time and space, other, relatively minor misunderstandings distort our sense of the world. Consider the American failure to convert to the metric system. Like all schoolchildren of my vintage, I spent many days listening to teachers explain litres and metres and hectares and all the other logical units of measurement, and then promptly forgot about it. All of us did, except the scientists, who always use such units. As a result, if I read that there will be a rise of 0.8 degrees Celsius in the temperature between now and the year 2000, it sounds less ominous than a rise of a degree and a half Fahrenheit. Similarly, a ninety-centimetre rise in sea level sounds less ominous than a one-yard rise—and neither of them sounds all that ominous until one stops to think that over a beach with a normal slope such a rise would bring the ocean ninety metres (that's two hundred and ninety-five feet) above its current tideline. In somewhat the same way, the logarith-

DEATH OF A SALESPERSON

mic scale we use to determine the acidity or alkalinity of our soils and our waters—pH—distorts reality for anyone who doesn't use it on a daily basis. Normal rainwater has a pH of 5.6. But the acidified rain that falls on Buck Hill, behind my house, has a pH of 4.6 to 4.2, which is from ten to fourteen times as acid as normal.

Of all such quirks, though, probably the most significant is an accident of the calendar: we live too close to the year 2000. Forever we have read about the year 2000. It has become a symbol of the bright and distant future, when we will ride in air cars and talk on video phones. The year 2010 still sounds far off, almost unreachably far off, as if it were on the other side of a great body of water. But 2010 is as close as 1970—as close as the breakup of the Beatles—and the turn of the century is no farther in front of us than Ronald Reagan's election to the Presidency is behind. We live in the shadow of a number, and that makes it hard to see the future.

Our comforting sense, then, of the permanence of our natural world—our confidence that it will change gradually and imperceptibly, if at all—is the result of a subtly warped perspective. Changes in our world which can affect us can happen in our lifetime—not just changes like wars but bigger and more sweeping events. Without recognizing it, we have already stepped over the threshold of such a change. I believe that we are at the end of nature.

By this I do not mean the end of the world. The rain will still fall, and the sun will still shine. When I say "nature," I mean a certain set of human ideas about the world and our place in it. But the death of these ideas begins with concrete changes in the reality around us, changes that scientists can measure. More and more frequently, these changes will clash with our perceptions, until our sense of nature as eternal and separate is finally washed away and we see all too clearly what we have done.

Svante Arrhenius took his doctorate at the University of Uppsala in 1884. His thesis earned him the lowest possible grade short of outright failure. Nineteen years later, the same thesis, which was on the conductivity of solutions, earned him a Nobel Prize. He later explained the initial poor reception: "I came to my professor, Cleve, whom I admired very much, and I said, 'I have a new theory of electrical conductivity as a cause of chemical reactions.' He said, 'This is very interesting,' and then he said, 'Goodbye.' He explained to me later that he knew very well that there are so many different theories formed, and that they are almost all certain to be wrong, for after a short time they disappeared; and therefore, by using the statistical manner of forming his ideas, he concluded that my theory also would not exist long."

Arrhenius's understanding of electrolytic conduction was not his only shrug-provoking new idea. As he surveyed the first few decades of the Industrial Revolution, he realized that man was burning coal at an unprecedented rate—"evaporating our coal mines into the air." Scientists already knew that carbon dioxide, a by-product of fossil-fuel combustion, trapped solar infrared radiation that would otherwise have been reflected back to space. The French polymath Jean-Baptiste-Joseph Fourier had speculated about the effect nearly a century before, and had even used the hothouse metaphor. But it was Arrhenius, employing measurements of infrared radiation from the full moon, who did the first calculations of the possible effects of man's stepped-up production of carbon dioxide. The average global temperature, he concluded, would rise as much as nine degrees Fahrenheit if the amount of carbon dioxide in the air doubled from its pre-industrial level; that is, heat waves in mid-American latitudes would run as high as a hundred and thirty degrees, the seas would rise several metres, crops would wither in the fields.

This idea floated in obscurity for a very long time. Now and then, a scientist took it up—the British physicist G. S. Callendar speculated in the nineteen-thirties that rising carbon-dioxide levels could account for the warming of North America and northern Europe which meteorologists had begun to observe in the eighteen-eighties. But that warming seemed to be replaced by a decline, beginning in the nineteen-forties; in any case, we were too busy creating better living through petroleum to be bothered with such long-term speculation. And the few scientists who did consider the matter concluded that the oceans, which hold much more carbon dioxide than the

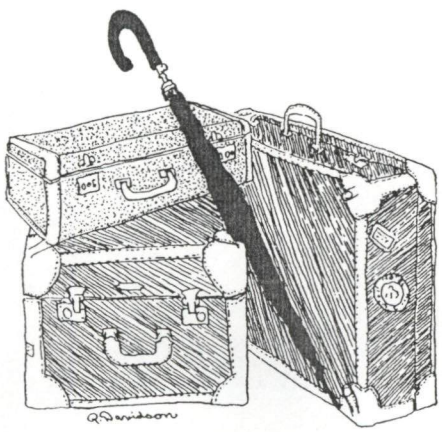
atmosphere, would soak up any excess that man churned out—that the oceans were an infinite sink down which to pour the problem.

Then, in 1957, two scientists at the Scripps Institution of Oceanography, in California, Roger Revelle and Hans Suess, published a paper in the journal *Tellus* on this question of the oceans. What they found may turn out to be the single most important limit in an age of limits. They found that the conventional wisdom was wrong: the upper layer of the oceans, where the air and sea meet and transact their business, would absorb less than half of the excess carbon dioxide produced by man. "A rather small change in the amount of free carbon dioxide dissolved in seawater corresponds to a relatively large change in the pressure of carbon dioxide at which the oceans and atmosphere are at equilibrium," they wrote. That is to say, most of the carbon dioxide being pumped into the air by millions of smokestacks, furnaces, and car exhausts would stay in the air, where, presumably, it would gradually warm the planet. "Human beings are now carrying out a large-scale geophysical experiment of a kind that could not have happened in the past nor be repeated in the future," they concluded, adding, with the morbid dispassion of true scientists, that this experiment, "if adequately documented, may yield a far-reaching insight into the processes of weather and climate." While there are other parts to this story—the depletion of the ozone, acid rain, genetic engineering—the story of the end of nature centers on this greenhouse experiment, with what will happen to the weather.

WHEN we drill into an oil field, we tap into a vast reservoir of organic matter—the fossilized remains of aquatic algae. We unbury it. When we burn oil—or coal, or methane (natural gas)—we release its carbon into the atmosphere in the form of carbon dioxide. This is not pollution in the conventional sense. Carbon monoxide is pollution—an unnecessary by-product; a clean-burning engine releases less of it. But when it comes to carbon dioxide a clean-burning engine is no better than the motor in a Model T. It will emit about five and a half pounds of carbon in the form of carbon dioxide for every gallon of gasoline it consumes. In the course of about a hundred years, our various engines and industries have released a very large portion of the carbon buried over the last five hundred million years. It is as if someone had scrimped and saved his entire life and then spent everything on one fantastic week's debauch. In this, if in nothing else, wrote the great biologist A. J. Lotka, "the present is an eminently atypical epoch." We are living on our capital, as we began to realize during the oil crises of the nineteen-seventies. But it is more than waste, more than a binge. We are spending that capital in such a way as to alter the atmosphere.

There has always been, at least since the start of life, a certain amount of carbon dioxide in the atmosphere, and it has always trapped a certain amount of the sun's radiation to warm the earth. If there were no atmospheric carbon dioxide, our world might resemble Mars: it would probably be so cold as to be lifeless. A little greenhouse effect is a good thing—life thrives in its warmth. The question is: How much? On Venus, the atmosphere is ninety-seven per cent carbon dioxide. As a result, it traps infrared radiation a hundred times as efficiently as the earth's atmosphere, and keeps the planet a toasty seven hundred degrees warmer than the earth. The earth's atmosphere is mostly nitrogen and oxygen; it is only about .035 per cent carbon dioxide, which is hardly more than a trace. The worries about the greenhouse effect are worries about raising that figure to .055 or .06 per cent, which is not very much. But enough, it turns out, to make everything different.

In 1957, when Revelle and Suess wrote their paper, no one even knew for certain whether carbon dioxide was increasing. The Scripps Institution hired a young researcher, Charles Keeling, and he set up monitoring stations at the South Pole and on the side of Mauna Loa, in Hawaii, eleven thousand feet above the Pacific. His data soon confirmed their hypothesis: more and more carbon dioxide was entering the atmosphere. When the first readings were taken, in 1958, the atmosphere at Mauna Loa contained about three hundred and fifteen parts per million of carbon dioxide. Subsequent readings showed that each year the amount increased, and at a steadily growing rate. Initially, the annual increase was about seven-tenths of a part per million; in recent years, the rate has doubled, to one and a half parts per million. Admittedly, one and a half parts per million sounds absurdly small. But scientists, by drilling holes in glaciers and testing the air trapped in ancient ice, have calculated that the carbon-dioxide level in the atmosphere prior to the Industrial Revolution was about two hundred and eighty parts per million, and that this was as high a level as had been recorded in the past hundred and forty thousand years. At a rate of one and a half parts per million per year, the pre-Industrial Revolution concentration of carbon dioxide would double in the next hundred and forty years. Since, as we have seen, carbon dioxide at a very low level largely determines the climate, carbon dioxide at double that very low level, small as it is in absolute terms, could have an enormous effect.



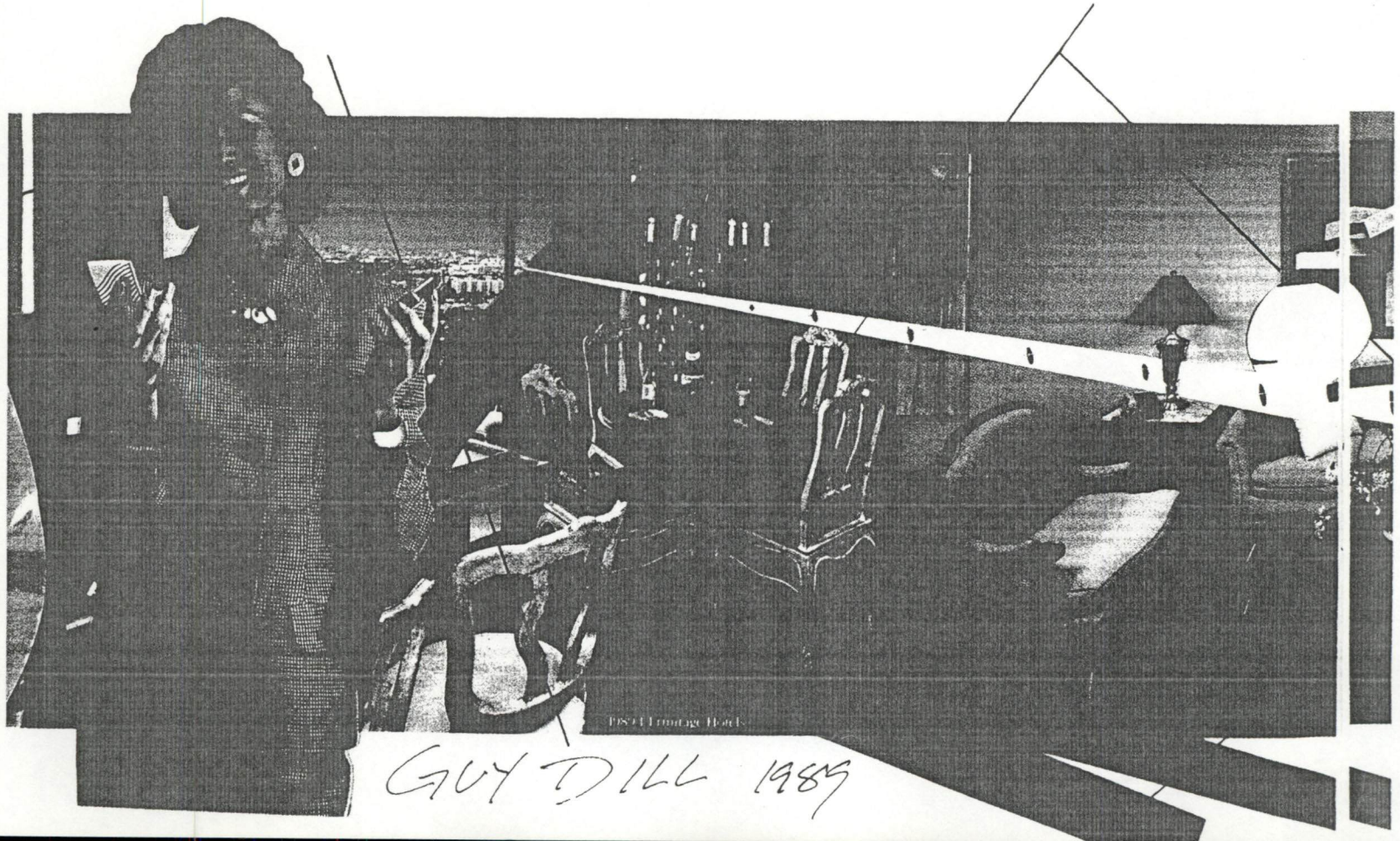
And the annual increase seems nearly certain to go higher. The essential facts are demographic and economic, not chemical. The world's population has more than tripled in this century, and is expected to double, and perhaps triple again, before reaching a plateau in the next century. Moreover, the tripled population has not contented itself with using only three times the resources. In the last hundred years, industrial production has grown fiftyfold. Four-fifths of that growth has come since 1950, almost all of it based on fossil fuels. In the next half century, a United Nations commission predicts, the planet's thirteen-trillion-dollar economy will grow five to ten times larger.

These facts are almost as stubborn as the chemistry of infrared absorption. They mean that the world will use more energy—two to three per cent more a year, by most estimates. And the largest increases may come in the use of coal—which is bad news, since coal

spews more carbon dioxide into the atmosphere than any other fuel. China, which has the world's largest hard-coal reserves and recently passed the Soviet Union as the world's largest coal producer, has plans to almost double coal consumption by the year 2000. A model devised by the World Resources Institute predicts that if energy use and other contributions to carbon-dioxide levels continue to grow very quickly, the amount of atmospheric carbon dioxide will have doubled from its pre-Industrial Revolution level by about 2040; if they grow somewhat more slowly, as most estimates have it, the amount will double by about 2070. And, unfortunately, the solutions are neither obvious nor easy. Installing some kind of scrubber on a power-plant smokestack to get rid of the carbon dioxide might seem an obvious fix, except that a system that removed ninety per cent of the carbon dioxide would reduce the effective capacity of the plant by eighty per cent. One often heard suggestion is to use more nuclear power. But, because so much of our energy is consumed by automobiles and the like, even if we mustered the political will and the economic resources to quickly replace each of our non-nuclear electric plants with nuclear ones our carbon-dioxide output would fall by only about thirty per cent. The same argument would apply, at least initially, to fusion or any other clean method of producing electricity.

Burning fossil fuels is not the only method human beings have devised to increase the level of atmospheric carbon dioxide. Burning down a forest also sends clouds of carbon dioxide into the air. Trees and shrubby forests still cover forty per cent of the land on earth, but the forests have shrunk by about a fifth since pre-agricultural times, and the shrinkage is accelerating. In the Brazilian state of Pará, for instance, nearly seventy thousand square miles were deforested between 1975 and 1986; in the hundred years preceding that decade, settlers had cleared about seven thousand square miles. The Brazilian government has tried to slow the burning, but it employs fewer than nine hundred forest wardens in an area larger than Europe.

This is not news; it is well known that the rain forests are disappearing, and are taking with them a majority of the world's plant and animal species. But forget for a moment that we are losing a unique resource, a cradle of life, irreplaceable grandeur, and so forth. The dense, layered rain forest contains from three to five times as much carbon per acre as an open, dry forest—an acre of Brazil in flames equals between three and five acres of Yellowstone. Deforestation currently adds about a billion tons of carbon to the atmosphere annually, which is twenty per cent or more of the amount produced by the burning of fossil fuels. And that acre of rain forest, which has poor soil and can support crops for only a few years, soon turns to desert or to pastureland. And where there's pasture there are cows. Cows support in their stomachs huge numbers of anaerobic bacteria, which break down the cellulose that cows chew. That is why cows, unlike people, can eat grass. The bugs that digest the cellulose excrete methane, the same natural gas we use as fuel. And unburned methane, like carbon dioxide, traps infrared radiation and warms the earth. In fact, methane is twenty times as efficient as carbon



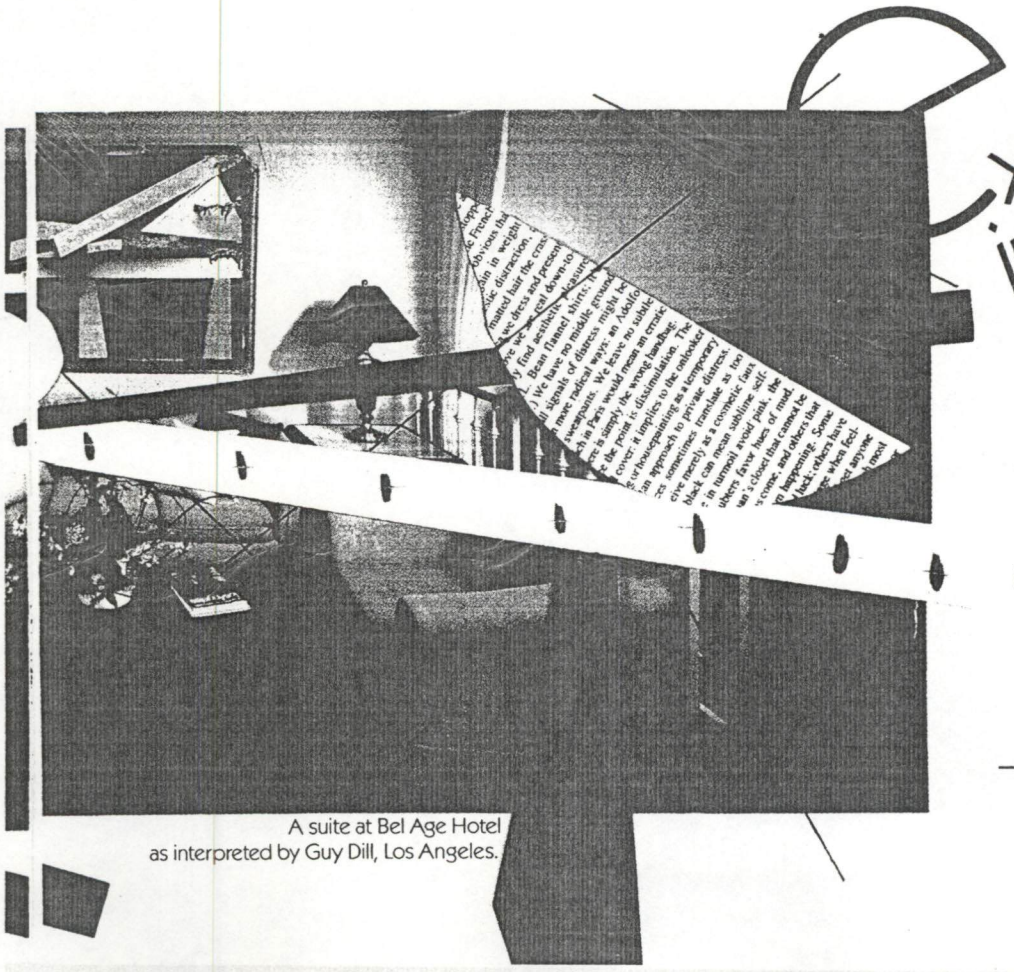
dioxide at warming the planet, so even though it makes up less than two parts per million of the atmosphere it can have a significant effect. Though it may come from seemingly "natural" sources—the methanogenic bacteria—the present huge numbers of these bacteria are man's doing. Mankind owns well over a billion head of cattle, not to mention a large number of camels, horses, pigs, sheep, and goats; together, they belch about seventy-three million metric tons of methane into the air each year—a four-hundred-and-thirty-five-per-cent increase in the last century.

We have raised the number of termites, too. Like cows, termites harbor methanogenic bacteria, which is why they can digest wood. We tend to think of termites as house-wreckers, but in most of the world they are house-builders, erecting elaborate, rock-hard mounds twenty or thirty feet high. If a bulldozer razes a mound, worker termites can rebuild it in hours. Like most animals, they seem limited only by the supply of food. When we clear a rain forest, all of a sudden there is dead wood everywhere—food galore. As deforestation has proceeded, termite numbers have boomed; Patrick Zimmerman, of the National Center for Atmospheric Research, in Boulder, Colorado, estimates that there is more than half a ton of termites for every man, woman, and child on earth. Termites excrete phenomenal amounts of methane: a single mound may give off five litres a minute.

Researchers differ on the importance of termites as a methane source, but they agree about rice paddies. The oxygenless mud of marsh bottoms has always sheltered the methane-producing bacteria. (Methane is sometimes known as swamp gas.) But rice paddies may be even more efficient; the rice plants themselves act a little like straws, venting as much as a hundred and fifteen million tons of methane annually. And rice paddies must increase in number and size every year, to feed the world's growing population. Then, there are landfills. Twenty per cent of a typical landfill is putrescible: it rots, creating carbon dioxide and methane. At the main New York City landfill, on Staten Island, the methane is pumped from under the trash straight to the stoves of thousands of homes, but at most landfills it just seeps out.

What's more, some scientists have begun to think that these sources by themselves may not account for all the methane. For one thing, an enormous amount of methane is locked up as hydrates in the tundra and in the mud of the continental shelves. These are, in essence, methane ices; the ocean muds alone may hold ten trillion tons of methane. If the greenhouse effect warms the oceans, if it begins to thaw the permafrost, then those ices could start to melt. Some estimates of the potential methane release from the ocean muds run as high as six hundred million tons a year—an amount that would more than double the present atmospheric concentration. This would be a nasty example of a feedback loop: warm the atmosphere and release methane; release methane and warm the atmosphere; and so on.

When all the sources of methane are combined, we have done an even more dramatic job of increasing methane than of increasing carbon dioxide. Samples of ice from Antarctic glaciers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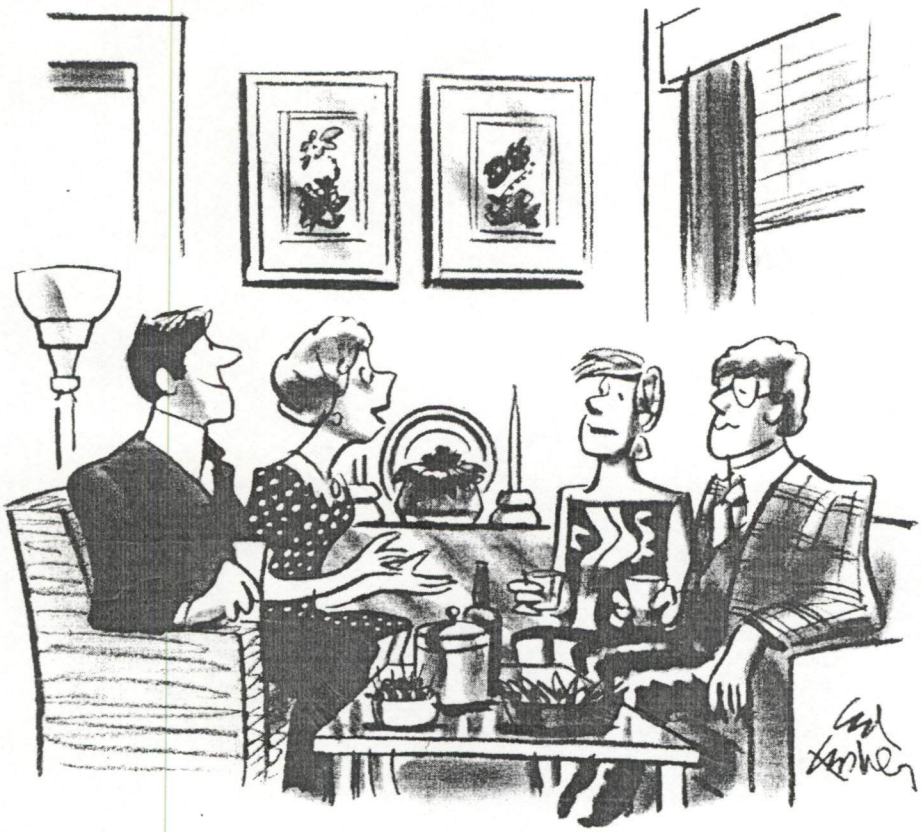

"We used to be old-fashioned. Now we're postmodern."

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show that the concentration of methane in the atmosphere has fluctuated between 0.3 and 0.7 parts per million for the last hundred and sixty thousand years, reaching its highest levels during the earth's warmest periods. In 1987, methane composed 1.7 parts per million of the atmosphere; that is, there is now two and a half times as much methane in the atmosphere as there was at any time since the onset of the ice age preceding the most recent one. The level is now increasing at a rate of one per cent a year.

Man is also pumping smaller quantities of other greenhouse gases into the atmosphere. Nitrous oxide, the chlorofluorocarbons—which are notorious for their ability to destroy the planet's ozone layer—and several more all trap warmth with greater efficiency than carbon dioxide. Methane and the rest of these gases, even though their concentrations are small, will together account for fifty per cent of the projected greenhouse warming. They are as much of a problem as carbon dioxide. And as all these compounds warm the atmosphere it will be able to hold more water vapor—itself a potent greenhouse gas. The British Meteorological Office calculates that this extra water vapor will warm the earth two-thirds as much as the carbon dioxide alone.

MOST discussion of the greenhouse gases rushes immediately to their future consequences, without pausing to let the simple fact of what has already happened sink in: the air around us—even where it's clean, and smells like spring, and is filled with birds—is significantly changed. We have substantially altered the earth's atmosphere.

That said, the question of what this new atmosphere means must arise. The direct effects are unnoticeable. Anyone who lives indoors breathes carbon dioxide at a level several times the atmospheric concentration without suffering any harm; the federal government limits industrial workers to a chronic exposure of five thousand parts per million, or almost fifteen times the current atmospheric level. A hundred years from now, a child at recess will still breathe far less carbon dioxide than a child in a classroom. This, however, is only mildly good news. Changes in the atmosphere will change the weather, and *that* will change recess. The weather—the temperature, the amount of rainfall, the speed of the wind—will change. The chemistry of the atmosphere may seem an abstraction, a text written in a foreign language. But its translation into the weather of New York and Cincinnati and San Francisco will change the life of each of us.

Theories about the effects all begin with an estimate of expected warming. The wave of concern that began with Revelle and Suess's article and Keeling's Mauna Loa and South Pole data has led to the development of complex computer models of the entire globe. The models agree that when, as has been predicted, carbon dioxide (or the equivalent combination of carbon dioxide and other greenhouse gases) doubles from the pre-Industrial Revolution level, the average global temperature will increase, and that the increase will be one and a half to five and a half degrees Celsius, or three to ten degrees Fahrenheit. Perhaps the most famous of these computer models has been constructed by James Hansen and his colleagues at the National Aeronautics and Space Administration's Goddard Institute for Space Studies. Even though it remains a rough simulation of the real world, they have improved it to the point where they are willing to forecast not just the effects of a doubling of carbon dioxide but the incremental effects along the way—that is, not just the forecast for 2050 but the one for 2000.

Take Dallas, for instance. According to Hansen's calculations, the doubled level of gases would increase the annual number of days with temperatures above 100°F. from nineteen to seventy-eight. On sixty-eight days, as opposed to the current four, the nighttime temperature wouldn't fall below 80°F. A hundred and sixty-two days a year—half the year, essentially—the temperature would top 90°F. New York City would have forty-eight days a year above the ninety-degree mark, up from fifteen at present. And so on. This would clearly change the world as we know it. One of Hansen's colleagues told reporters, "It reaches a hundred and twenty degrees in Phoenix now. Will people still live there if it's a hundred and thirty degrees? A hundred and forty?" (And such heat waves are possible even if the average global increase, figured over a

year, is only a couple of degrees, since any average conceals huge swings.) These changes, Hansen and his colleagues said in a paper published last fall in the *Journal of Geophysical Research*, should begin to be obvious to the man in the street by the early nineteen-nineties; that is, the odds of a very hot summer will, thanks to the greenhouse effect, become better than even beginning now.

In recent years, there have, of course, been any number of doom-laden prophecies that haven't come true—oil is selling at eighteen dollars a barrel, half its price just a few years ago. Is the warming theory valid? The obvious way to check is to measure the temperature and see if it's going up. But this is easier said than done. In the first place, the warming doesn't show up immediately. The oceans can hold a lot of heat; the warming so far may be stored there, ready to re-radiate out to the atmosphere, the way the sun's heat is held through the night by a rock. This "thermal lag" may be as little as ten years, as much as a hundred. And when you check the thermometers it won't do to measure only a few places for only a few years, because climate is "noisy"—full of random fluctuations. (If you had spent this summer in Tucson, for example, you would have been sure that something was happening: the city set forty-seven high-temperature records. New York, by contrast, has had fairly normal summer temperatures.) To find what climatologists call the "warming signal" through the static of naturally cold and hot years requires an enormous effort. Two such studies have been done—one by Hansen and his NASA colleagues, the other at the University of East Anglia. The studies reach back to 1880, when scientists first began systematic weather observations. To find truly global averages, they include readings from thousands of land-based and shipboard monitoring stations. Both studies conclude that the earth's temperature increased a little more than a degree Fahrenheit from 1880 to 1980. This is consistent with what most of the greenhouse models indicate. Updates of both studies show that the four warmest years on record occurred in the nineteen-eighties; the rise is accelerating as more gases enter the air, just as the models indicate. The British study lists the six warmest years on record as (in descending order) 1988, 1987, 1983, 1981, 1980, and 1986.

In 1988, the American drought hit the heart of the Grain Belt, where most of the nation's and much of the world's food is grown. It followed a dry fall and winter, so its effects were quickly evident; the Mississippi River, for example, sank to its lowest level since 1872, when the Navy began taking measurements. And just about the time that the pictures on television began to grab everyone's attention it got very, very hot in the urban East, where those in the government and the media establishment, among others, have their homes. It happened that in late June, as the anxiety intensified—newscasters telling us that the next two weeks were crucial for corn pollination, meteorologists issuing pessimistic sixty-day forecasts—the Senate Committee on Energy and Natural Resources held a hearing on the greenhouse effect. It was actually the second part of the hearing. Part I had been held the previous November, when, according to the Louisiana Democrat J. Bennett

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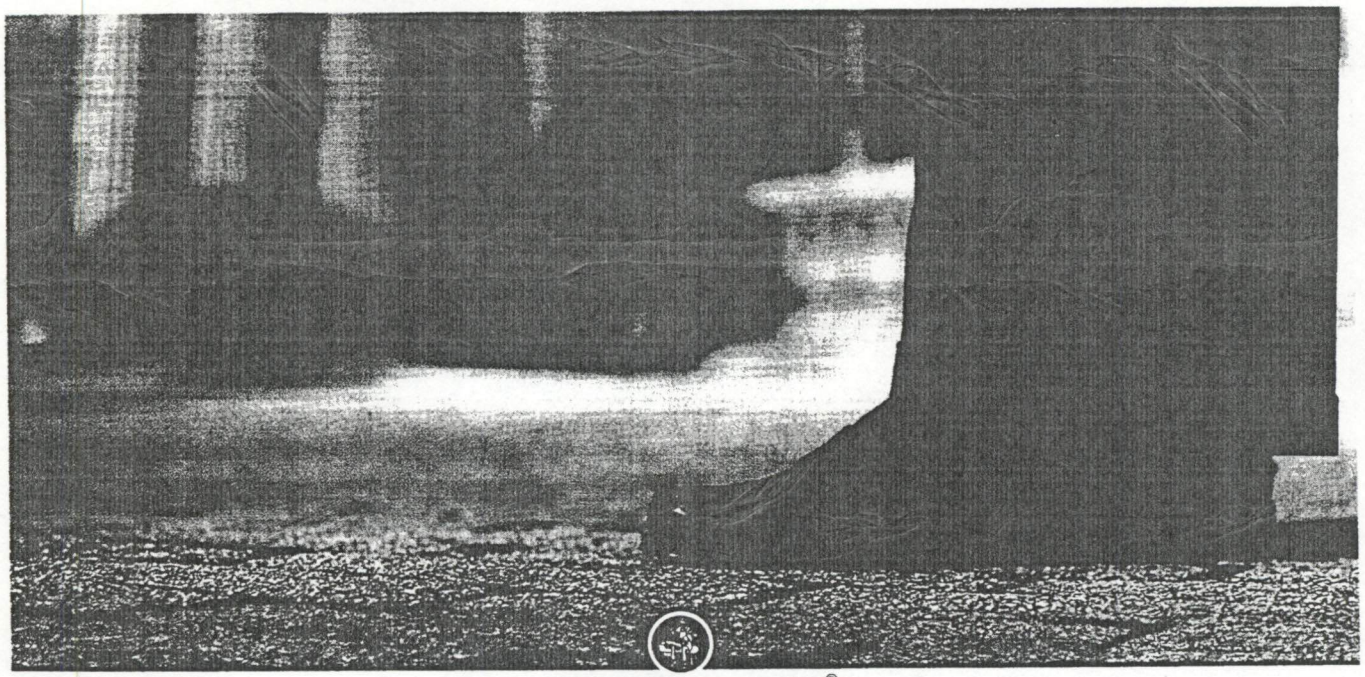

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Johnston, the senators listened with "concern" as they were told that one expected result of the greenhouse effect would be a drying of the Midwest and the Southeast. But now, "as we experience a-hundred-and-one-degree temperatures in Washington, D.C., and [reduced] soil moisture across the Midwest is ruining the soybean crops, the corn crops, the cotton crops," Senator Johnston said, concern was giving way to "alarm." Several of the senators said that they had already read the report of Dr. Hansen, the chief witness, and predicted that it would startle listeners. Hansen's report, Dale Bumpers, of Arkansas, said, should be "cause for headlines in every newspaper in America tomorrow morning." As it turned out, he was not exaggerating. Hansen testified that he was ready to state that the warming signal was beginning to emerge above the noise of normal weather, that there was only a one per cent chance that the temperature increases seen in the last few years were accidental, and that we now lived in the greenhouse world.

It was a claim no other established scientist had made—certainly not one on a government payroll. The reaction was much as the senators had expected. The next day's *Times*, for instance, ran a story at the top of the front page under the headline "GLOBAL WARMING HAS BEGUN, EXPERT TELLS SENATE." The message was finally getting across, nearly a century after Arrhenius and three decades after Revelle and Suess. But the heat of the day may have been a mixed blessing; though it focussed everyone's attention on the issue, it also led most people to think that what Hansen had said was that the heat and drought of 1988 were greenhouse-related. Strictly speaking, that is not what he had testified to. "It is not possible to blame a specific heat wave or drought on the greenhouse effect," he said—and, indeed, some experts think that the drought and heat of 1988 were mainly the result of a fluctuation of tropical ocean currents which steered the North American jet stream, with its cargo of rainstorms, north of the Great Plains.

What we *can* blame the carbon dioxide and the methane for is a longer-range pattern. Even if the summer of 1988 had been cool and damp, even if there had been mushrooms growing in the wheat fields of Kansas, Hansen would have said the same thing. What had convinced him was not the devastation in the Midwest or the misery in the Eastern cities but the numbers that his computer kept spitting at him. "There are two time scales to consider," he explained, some months after giving his testimony. "One is the last three complete decades, for which the natural variability in temperature has been calculated—it is about point thirteen degrees Celsius. This coincides roughly with the thirty years for which we have precise measurements of carbon dioxide and other gases. And our readings show that the global mean temperature has risen about point four degrees in the three-decade period. The other is the larger record—the observations back to the eighteen-eighties. Over that period, there's been about a point-six-degree-Celsius rise. Now, over a longer period there's also more natural variability—sources like fluctuations in solar activity, deep ocean circulation, and so forth." The standard deviation over the longer period, he noted, was about .2°C. So in both cases Hansen's observed rise was almost exactly three times the standard deviation. "There's no magic point where you pick out the signal," he said. "But when it gets to three sigma—when it gets to three times the standard deviation—you're getting to a level where it's unlikely to be an accidental warming."

Some recent studies tend to agree with Hansen's conclusion that the warming has already begun: precipitation appears to have increased above 35 degrees north latitude and decreased below it since the early nineteen-fifties, for instance—a result anticipated in the greenhouse models. And some investigators have found a "variable but widespread" warming of the Alaskan permafrost, which changes temperature much more slowly than the air and thus may provide a better record.

But not all scientists—not even all those committed to the greenhouse theory—believe that the warming has already begun. Hansen, though well respected, is out on a limb, if a fairly stout one. Some have taken issue with his use of statistics, and others with his outspokenness. At a workshop on global warming at Amherst College this spring, the assembled climatologists concluded that while it was "tempting to attribute" the recent warm years to the greenhouse effect "such an attribution

cannot now be made with any degree of confidence." Stephen Schneider, a senior scientist at the National Center for Atmospheric Research and a longtime proponent of the greenhouse theory, offers a gambler's analogy: the warm years of the nineteen-eighties, he says, are not "proof" of a warming any more than a dealer's drawing four aces "proves" that he's dealing from the bottom of the deck. "Different tastes cause some people to accept the reality of a hypothesized climatic change at a low signal-to-noise ratio, whereas others might not believe in the reality of the change until a large signal has persisted for a very long time," Schneider told the Senate two months after Hansen testified. "Quite simply, accepting any particular signal-to-noise ratio as 'proof' of global warming reflects the personal judgment of the investigator."

Kenneth Watt, a professor of zoology and environmental studies at the University of California at Davis, says that studies such as Hansen's fail to correct enough for the "urban-heat-island effect"—a phenomenon well known to meteorologists, in which, as cities grow up around thermometers, concrete and exhaust skew readings. There's also no guarantee that other factors—solar flares, perhaps, which coincide with both warming and cooling trends, or the strong El Niño current of recent years—aren't skewing the readings. Last January, Tim Barnett, a climatologist at Scripps, correctly forecast much cooler low-latitude temperatures for the first part of this year as a result of "La Niña," a tropical "cold event" that is the opposite of El Niño. During the summer of 1988, in some parts of the ocean off equatorial South America the water temperature dropped 7°F. Hansen saw the dip in his computer data, and he agrees that it may make this year's over-all readings go down. "But such things are bumps," he says.

But few of the objections are to the theory as a whole. Everyone in the scientific community agrees that carbon dioxide is on the rise, and almost everyone believes that the rise cannot help having some effect. An occasional scientist says that the onset of the effect may be delayed as much as forty years, but this is considerably different from dismissing it. Last May, Hansen returned to Capitol Hill to tell the Senate's Science, Technology, and Space Subcommittee that his studies showed a definite danger of future drought. The White House tried to alter his testimony, arguing that, in the words of the Presidential press secretary, Marlin Fitzwater, "there are many points of view on the global-warming issue." But Fitzwater didn't cite any studies undercutting Hansen's, and the same day Stephen Schneider assured the subcommittee that "there is virtually no scientific controversy" over the contention that more carbon dioxide in the atmosphere will produce higher temperatures. "That's not a speculative theory," he said.

THERE is debate, though, over the question of what will happen as the heating begins. A large-scale change in the climate will set off a series of other changes, and while some of these would make the problem worse, others might lessen it. Skeptics are inclined to argue that the warming will trigger some natural compensatory brake. S. Fred Singer, a professor of environmental sciences at the University of Virginia, has assumed a part-time role as greenhouse curmudgeon, expressing his doubts to reporters and on various Op-Ed pages. He grants that the earth's temperature should increase "provided that all other factors remain the same." But, he says, they won't. "For example, as oceans warm and more water vapor enters the atmosphere, the greenhouse effect will increase somewhat, but so should cloudiness—which can keep out incoming solar radiation and thereby reduce the warming." There are other possibilities. "The feedbacks are enormously complicated," Michael MacCracken, of the Lawrence Livermore National Laboratory, in California, told *Time* in 1987. "It's like a Rube Goldberg machine in the sense of the number of things that interact in order to tip the world into fire or ice."

Apéritif

The computer models have tried to incorporate such factors. In some cases, Hansen admits, we simply don't have enough knowledge to make more than educated guesses; the behavior of the oceans is something of a wild card, and so are the clouds. (The difficulty of estimating cloud feedback is a major reason that most warming predictions are expressed as a range of temperatures, and not as a single number.) But almost every doubt is double-edged. Low-level stratocumulus clouds reflect a lot of solar radiation and might tend to cool the earth. Monsoon clouds, on the other hand, are long and thin, and let in the sun's heat while preventing its escape. Hansen's work suggests that the over-all effect of clouds will be to increase the warming.

A variety of other feedback effects have also been identified and tallied

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up. For instance, every surface has an albedo—a degree to which it reflects light. A polar ice cap, or a white shirt, has a high albedo—a large proportion of the sun's rays are reflected back into space. If the ice is replaced by dark-blue ocean, more heat will be absorbed. Tropical rain forests absorb a lot of heat now; if they turn to deserts, these deserts will reflect heat. The feedbacks are *products* of the warming signal, and are distinct from phenomena that always have affected and always will affect temperature—volcanoes, say, which can throw up so much dust that it acts as a veil, or El Niños, or solar flares. In any event, the warming estimates provided by the computer models are not worst-case scenarios. They are the middle ground. Stephen Schneider told the Senate energy committee last year that it was "equally likely" that the warming forecasts were too low as that they were too high.

Some of the potential feedbacks are so enormous that they may someday make us almost forget what originally caused the greenhouse warming. Twenty thousand years ago, the land that surrounds my house in the Adirondacks was covered by glaciers that had spread slowly down from Canada, and eventually retreated there. As the ice disappeared, "the fierce ruthlessness of nature gave way to a benevolent mood," in the words of a local writer. "Rains came over the years to chasten the harshness of the landscape. The startling gaping holes in the earth were filled with crystal-clear water. Soft green foliage came to clothe the naked rock-hewn slopes." This was a slow process, and is even now incomplete—some plant and animal species are still migrating up here. Great forests rose on the glacial till and soon created more soil for greater forests, and so on—a process that was first interrupted a couple of hundred years ago, when men began cutting down most of the Adirondack woods. But this interruption was only temporary; just before the turn of this century, New York State, in an early burst of environmental consciousness, began buying huge tracts of land in the Adirondacks and stipulating that they be "forever kept as wild"—off limits to loggers and real-estate developers alike. As a result, this area, though still threatened, is a happy exception—a reforested, replenished zone, a second-chance wilderness.

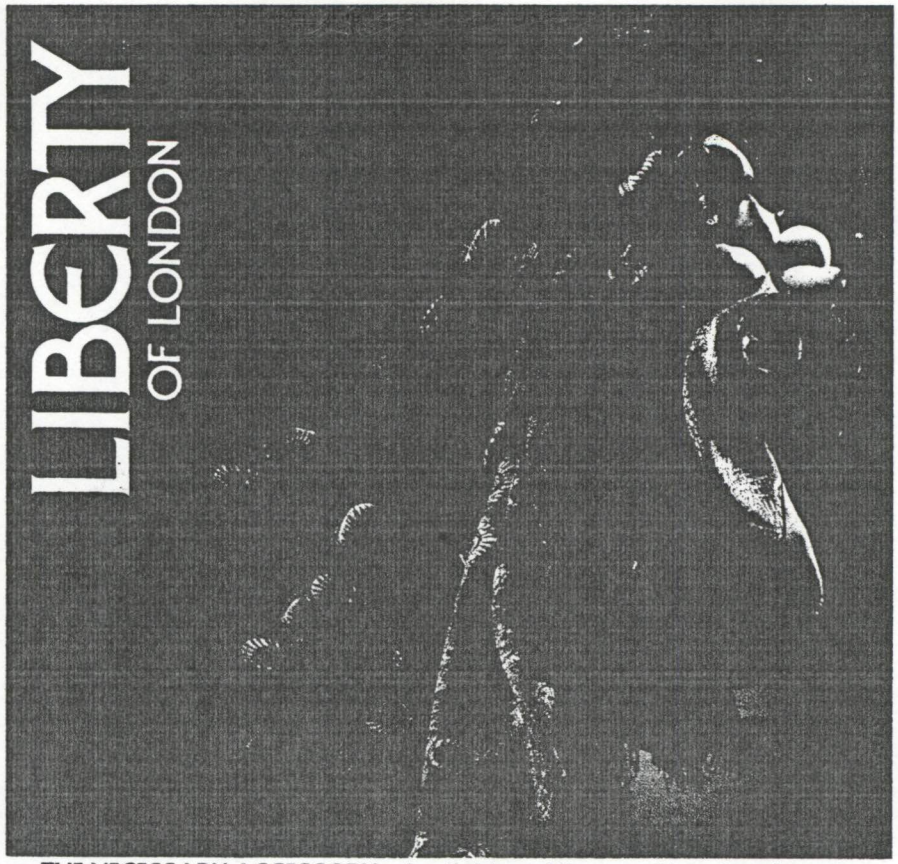
But the trees that live here don't do so because of the laws; they do so because of the climate. They have slowly marched north as the climate warmed since the end of the last ice age, and if it continued slowly warming they would slowly keep marching; the convoy of pines might march right out of here, and the mass of hardwoods found in lower Appalachian latitudes might march in to replace them. But before we get too used to this marching metaphor it is worth recalling that trees are rooted in the ground; forests move only by the slow growth of new trees along their edges. In a year, a forest moves, naturally, a half mile at most. Which is fine, if that's how slowly the climate is changing. The computer models, however, project an increase in average global temperature as high as one degree Fahrenheit per decade. An increase of one degree in average global temperature moves the climatic zone some thirty-five to fifty miles north. So if the temperature increases one degree per decade the forest surrounding my home would be due at the Canadian border by 2020, which is just about the time that we'd be expecting the trees from a hundred miles south to start arriving. They won't—half a mile a year is as fast as forests move. The trees outside my window will still be there, but they'll be dead or dying.

Eventually, perhaps within a few decades, forests—or, at least, scrub better adapted to the new conditions—will replace the forests that expired. But in the meantime those dead forests will release tremendous amounts of carbon to the atmosphere. Last year's Yellowstone fires released carbon amounting to 2.8 per cent of this country's annual emissions from fossil fuels; that is, in a dozen weeks, on only about a million and a half acres, the fires released as much carbon as ten days' worth of driving, home heating, factory production, motorboating, and so on. The world's forests, plants, and soil (which gives up its carbon much more rapidly as trees die) contain more than two trillion tons of carbon, probably more than a third of it in the middle and high latitudes. By contrast, the atmosphere at present contains only about seven hundred and fifty billion

tons. So even a fairly small change in the forests could substantially increase the amount of carbon dioxide in the atmosphere, intensifying the warming.

This vast decline, this forest "dieback," is not some distant proposition. A 1988 study issued by the World Meteorological Organization and the United Nations Environmental Program found that, given a fairly rapid warming, "reproductive failure and forest dieback is estimated to begin between 2000 and 2050." A University of Virginia study predicts what Michael Oppenheimer, of the Environmental Defense Fund, calls "biomass crashes" in the pine forests of the southeastern United States over the next forty years if the warming continues. Last September, James Hansen told reporters that the birch trees and many of the evergreens of the Northeast "may have a hard time surviving, even in the next ten to twenty years." There are signs—frightening signs—that some of the feedback loops are starting to kick in. In May, George Woodwell, a biologist at the Woods Hole Research Center, told the Senate's science-and-technology subcommittee that the annual one-and-a-half-parts-per-million increase in atmospheric carbon dioxide seemed to have surged upward in the last eighteen months to two and a half parts per million. "I'm suggesting that the warming of the earth is increasing the decay of organic matter," he said, adding that such an event had not been worked into the computer climate models—in other words, their estimates of future warming might well be too low.

For the moment, though, forget about the higher temperatures and the dead trees and the other effects. The physical consequences of increasing the level of carbon dioxide will be staggering, but no more staggering than the simple fact of what we have already done. Carbon-dioxide levels have gone up significantly, and globally. Elevated levels can be measured far from industry and miles above the ground. And the changes are irrevocable. They are not possibilities. They cannot be wished away, and they cannot be legislated away. To prevent them, we would have had to clean up our collective act many decades ago. We have done this ourselves—by driving our cars, running our factories, clearing our forests, growing our rice, turning on our air-



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conditioners. In the years since the Civil War, and especially in the years since the Second World War, we have changed the atmosphere—changed it enough so that the climate will change dramatically. Most of the major events of human history gradually lose their meaning: wars that seemed at the time all-important are now a series of dates that schoolchildren don't even try to remember; great feats of engineering crumble in the desert. But now the way of life of one part of the world in one half century is altering every inch and every hour of the planet.

MOST mornings, I hike up the hill outside my back door. Within a hundred yards, the woods swallow me up, and there is nothing to remind me of human society—no trash, no stumps, no fences, not even a real path. Looking out from the high places, you can't see road or house; it is a world apart from man. But once in a while someone will be cutting wood farther down the valley, and the snarl of a chain saw will fill the woods. It is harder these days to get caught up in the timelessness of the forest, for man is nearby. The sound of the chain saw doesn't blot out all the noises of the forest, or drive the animals away, but it does drive away the feeling that you are in another, separate, wild sphere.

Now that we have changed the most basic forces around us, the noise of that chain saw will always be in the woods. We have changed the atmosphere, and that is changing the weather. The temperature and the rainfall are no longer entirely the work of some uncivilizable force but instead are in part a product of our habits, our economies, our ways of life. Even in the most remote wilderness, where the strictest laws forbid the felling of a single tree, the sound of that saw will be clear, and a walk in the woods will be changed by its whine. The world outdoors will mean the same thing as the world indoors, the hill the same thing as the house. An idea can become extinct, just like an animal or a plant. The idea in this case is "nature"—the wild province, the world apart from man, under whose rules he was born and died. We have not ended rainfall or sunlight. The wind still blows—but not from some other sphere, some inhuman place. It is too early to tell exactly how much harder the wind will blow, how much hotter the sun will shine. That is for the future. But their *meaning* has already changed.

The argument that nature is ended is complex; profound objections to it are possible, and I will try to answer them. But to understand what is ending requires some attention to the past. Not the ancient past, not the big bang or the primal soup—the European exploration of the New World is far enough back, since it is man's *idea* of nature that is important to this discussion, and it was in response to that wild country that much of our modern notion of nature developed. North America was not unaltered by man when the Europeans arrived, but its previous occupants had treated it fairly well. Most of it was still wilderness on the eve of the Revolution, when William Bartram, one of America's first professional naturalists, set out from his native Philadelphia to tour the South. Though some of the land through which he travelled had been settled (he spent a number of nights on plantations), the settlement was sparse, and the fields of indigo and rice gave way quickly to wilderness—not the dark and forbidding wilderness of European fairy tales but a blooming, humming, fertile paradise. Every page of his diary of the journey through "North & South Carolina, Georgia, East & West Florida, the Cherokee Country, the Extensive Territories of the Muscogulges, or Creek Confederacy, and the Country of the Chactaws" shouts of the fecundity, the profligacy, of that fresh land: "I continued several miles [over] verdant swelling knolls, profusely productive of flowers and fragrant strawberries, their rich juice dyeing my horse's feet and ankles." When he stops for dinner, he picks a wild orange, and stews a fresh-caught trout in its juice over his fire.

Whatever direction he struck off in, Bartram found vigorous beauty. His diary brims over with the grand Latin binomials of a thousand plants and animals (*Kalmia latifolia*, "snowy mantled" *Philadelphus inodorus*, *Pinus sylvestris*, *Populus tremula*, *Rheum rhaponticum*, *Magnolia grandiflora*) and also with the warm common names —the bank martin, the water wagtail, the mountain cock, the chattering plover, the bumblebee. But the roll call of his adjectives is even more indicative of his mood. In the account of a single evening, he musters fruitful, fragrant,

sylvan (twice), moderately warm, exceeding pleasant, charming, fine, joyful, most beautiful, pale gold, golden, russet, silver (twice), ultramarine, velvet-black, orange, prodigious, gilded, delicious, harmonious, soothing, tuneful, sprightly, elevated, cheerful (twice), high and airy, brisk and cool, clear, sweet, and healthy. And where he can't see, he imagines marvels: the fish disappearing into subterranean streams, "where, probably, they are separated from each other, by innumerable paths, or secret rocky avenues; and after encountering various obstacles, and beholding new and unthought-of scenes of pleasure and disgust, after many days absence from the surface of the world emerge again from the dreary vaults, and appear exulting in gladness, and sporting in the transparent waters of some far distant lake." But he is no Disney—this is no "Fantasia." He is a scientist recording his observations, and words like "cheerful" and "sweet" seem to be technical descriptions of the untouched world in which he wandered.

This sort of joy in the natural world was not a literary convention, a given. Much of literature regarded wilderness as ugly and crude until the Romantic movement of the late eighteenth century; Andrew Marvell, for one, referred to mountains as "ill-designed excrescences." This silliness changed into a new silliness with the Romantics. Chateaubriand's immensely popular "Atala" describes the American wilderness as full of bears "drunk with grapes, and reeling on the branches of the elm trees." But the rapturous fever took on a healthier aspect in this country. Most of the pioneers, to be sure, saw a buffalo as something to hunt, a forest as something to cut down, a flock of passenger pigeons as a call for heavy artillery (farmers would bring their hogs to feed on the carcasses raining down in the slaughter), but there were always a good many—even, or especially, among the hunters and loggers—who recognized and described the beauty and order of this early time.

Of a thousand examples, my favorite single description comes from George Catlin, who travelled the frontier in the eighteen-thirties to paint the portraits of American Indians. In his journal he describes a valley, "far more beautiful than could have been *imagined* by mortal man," in which he

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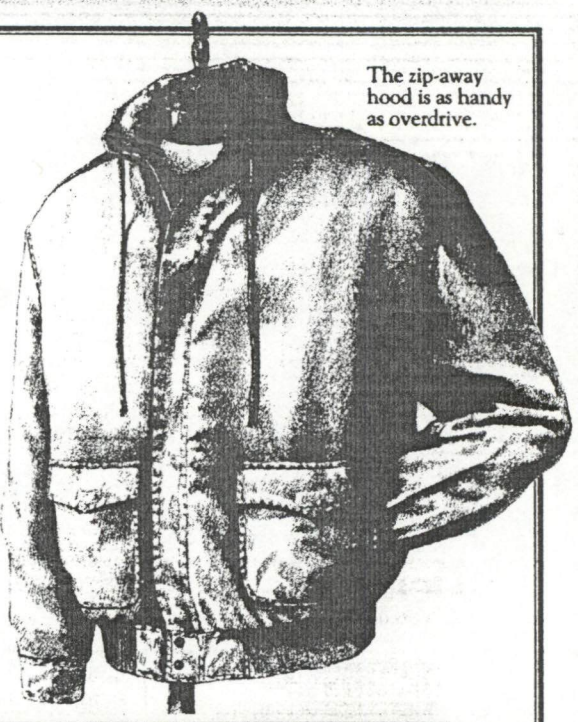
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spent the night on a ride north from Fort Gibson to the Missouri River:

> An enchanting little lawn of five or six acres, on the banks of a cool and rippling stream, that was alive with fish; and every now and then, a fine brood of young ducks, just old enough for delicious food, and too unsophisticated to avoid an easy and simple death. This little lawn was surrounded by bunches and copses of the most luxuriant and picturesque foliage, consisting of lofty *bois d'arcs* and elms, spreading out their huge branches, as if offering protection to the rounded groups of cherry and plum-trees that supported festoons of grapevines, with their purple clusters that hung in the most tempting manner over the green carpet that was everywhere decked out with wild flowers, of all tints and of various sizes, from the modest wild sun-flowers, with their thousand tall and drooping heads, to the lilies that stood, and the violets that crept beneath them. . . . The wild deer . . . were repeatedly rising from their quiet lairs, and bounding out, and over the graceful swells of the prairies which hemmed it in.

If this passage had a little number at the start of each sentence, it could be Genesis; it sticks in my mind as a baseline, a reminder of where we began.

Such visions of the world as it existed outside human history became scarcer with each year that passed. By 1929, when Bob Marshall, a co-founder of the Wilderness Society, set off to explore Alaska's Brooks Range, every stretch of the lower forty-eight had been visited, mapped, and named. Each day of his trek brought eight, ten, a dozen ridges and streams and peaks under his eye, and hence into human history:

> We discovered that Clear River emerged from none of the three gorges we had imagined, but from a hidden valley which turned almost at right angles to the east. I cannot convey in words my feeling in finding this broad valley lying there, just as fresh and untrammelled as at the dawn of geological eras hundreds of millions of years ago. Nor is there any adequate way of describing the scenery. . . . I could mention dozens of thousand-foot sheer precipices; I could liken the valley to a Yosemite without waterfalls, but with rock domes beside which the world-renowned Half Dome would be trivial—yet with all that, I would not have conveyed the sense of the continuous, exulting feeling of immensity. . . . Best of all it was fresh—gloriously fresh. At every step there was the exhilarating feeling of breaking new ground. There were no musty signs of human occupation. This, beyond a doubt, was an unbeaten path.

Marshall was very nearly the last person to see any part of this continent unpolluted even by the knowledge that someone had been there before. His explorations were a last echo of the journeys of discovery that had marked an earlier epoch. It is hard for us to believe that only a hundred and twenty years ago the valley of the Colorado River—the Grand Canyon—was a blank spot on maps of the Southwest, or that fifty years before that the Rockies were a rumor among white men. When Thoreau climbed Mt. Katahdin, in 1846, he could list the five white men who had preceded him to the peak. "I am reminded by my journey how exceedingly new this country still is," Thoreau wrote. "Those Maine woods differ essentially from ours [in Concord]. There you are never reminded that the wilderness which you are threading is, after all, some villager's familiar wood-lot, some widow's thirds, from which her ancestors have sledded fuel for generations, minutely described in some old deed." Nowadays, Katahdin, though preserved as a park, is so jammed with climbers that the authorities must limit their number; sometimes several hundred people are at the summit at once. On a holiday weekend, the trail up Mt. Marcy, the Adirondacks' highest peak, is like Macy's escalators with a heavy balsam scent.

Over time, though, we've reconciled ourselves to the idea that we'll not be the first up any hill. The wonder of nature does not depend on its freshness. The Grand Canyon is so grand that we don't mind not being the first people to see it. But still we feel the need for pristine places. We have legislated wilderness, set aside big tracts of land where, in the words of the federal statute, "the earth and its community of life are untrammelled by man." Even if we don't visit them, they matter to us. The Arctic National Wildlife Refuge, on Alaska's northern shore, is reached by just a few hundred people a year, but it has a vivid life in the minds of many more, who are upset that oil companies want to drill there. They are upset not only because it might harm the caribou but because here is a vast space free of roads and buildings and antennas—a blank spot.

When Rachel Carson wrote "Silent Spring," she was able to find some parts of the Arctic still untouched—no DDT in the fish, the beaver, the beluga, the caribou, the moose, the polar bear, the walrus. The cranberries, the salmonberries, and the wild rhubarb all tested clean, though two snowy owls, probably as a result of their migrations, carried small amounts of the

pesticide, as did fat samples from several Eskimos who had been away to the hospital in Anchorage. In other words, as pervasive a problem as DDT was and is, one could always imagine that somewhere a place existed free of its taint. (And, largely as a result of Carson's book, there are more and more such places.) As pervasive and growing as the problem of acid rain surely is, at the moment places still exist with a rainfall of an acceptable pH. And if we wished to stop acid rain we could: experimenters have raised tents over groves of trees to demonstrate that if the acid bath ceases a forest will return to normal. Even the radiation from an event as nearly universal as the explosion at the Chernobyl nuclear power plant has begun to fade, and Scandinavians can once more eat some of the vegetables they grow. The idea of wildness, then, can survive most of man's destruction of nature. If the ground is dusty and trodden, we look at the sky; if the sky is smoggy, we travel to some place where it's clear; if we can't travel to some place where it's clear, we imagine ourselves in Alaska or Australia or some other place where it is, and that works nearly as well. Nature is durable in our imaginations. The idea of wildness has outlasted the exploration of the entire globe. Standing in the middle of a grimy English mill town, George Orwell reflected, "In spite of hard trying, man has not yet succeeded in doing his dirt everywhere. The earth is so vast and still so empty that even in the filthy heart of civilization you find fields where the grass is green instead of grey; perhaps if you looked for them you might even find streams with live fish in them instead of salmon tins."

But now the basis of that faith is lost. The idea of nature will not survive the new, global pollution—the carbon dioxide and the methane and the like. This new rupture with nature is different both in scope and in kind from salmon tins in an English stream. We have deprived nature of its independence, and that is fatal to its meaning. Nature's independence *is* its meaning.

If you travel by plane and dog team and snowshoe to the farthest corner of the Arctic and it is a mild summer day, you will not know whether the temperature is what it is "supposed" to be or whether you are standing in the equivalent of a heated room. If the wind is howling and the temperature is twenty

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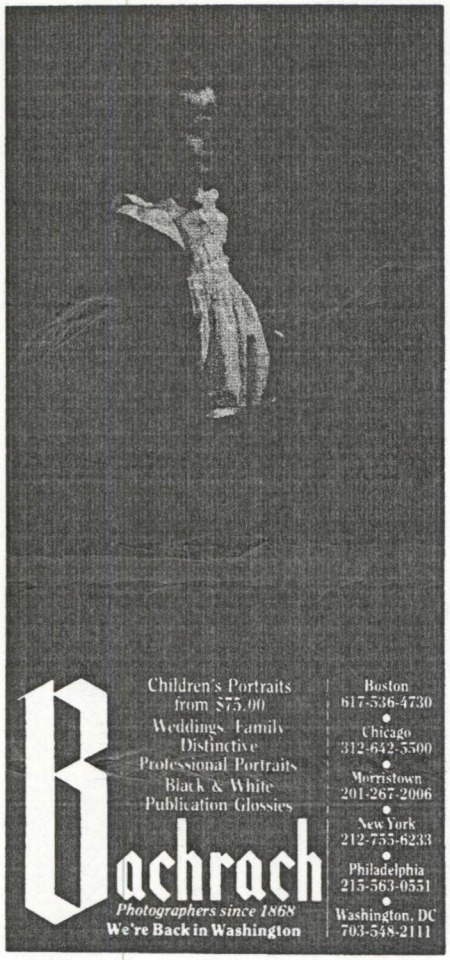

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below, might it otherwise be forty below? Since most of us get to the North Pole only in our minds, our situation is more like this: if, in July, there's a heat wave in London, it won't be a natural phenomenon. It will be a man-made phenomenon—an amplification of what nature intended, or a total invention. Or it *might* be a man-made phenomenon, which amounts to the same thing. The storm that could have snapped the hot spell may never form, or may veer off in some other direction—not by the laws of nature but by the laws of nature as rewritten by man. If the sun feels sweet on the back of your neck, well, that's fine, but it isn't nature. What has happened is the extinction of summer and its replacement with something else that will be called "summer." This new summer will retain some of the season's relative characteristics—it will be hotter than the rest of the year, for instance, and it will be the time of year when crops grow—but it will not be summer, just as even the best prosthesis is not a leg. Those "record highs" and "record lows" that the weathermen are always talking about are meaningless now. They imply a connection between the past and the present which doesn't exist. And, of course, climate determines an enormous amount of the rest of nature—where the forests stop and the tundra or the prairies begin, where the rain falls and where the arid deserts squat, where the wind blows strong and steady, where the glaciers form, how fast the lakes evaporate, and how high the seas rise.

About half a mile from my house, right at the head of a small lake, the town has installed a street light. It is the only one for miles, and it is a good thing that it is there; without it, a car or two each summer would miss the turn and end up in the drink. Still, it intrudes on the dark. Most of the year, once the summer people have left, there is not another light to be seen. On a starry night, the Milky Way stands out like a marquee; on a cloudy night, you can walk in pitch-black darkness, unable to see even the dog trotting at your side. But then, around a bend, there is the street lamp, breaking up the feeling of the night. And now it is as if we had put a huge lamp in the sky and cast that same prosaic light everywhere.

WE will have a hard time accepting this new state of affairs. Even the most far-seeing naturalists of an earlier day failed to comprehend that the atmosphere, the climate, could be dramatically altered. Thoreau, complaining about the logging that eventually destroyed almost every stand of virgin timber between the Atlantic and the Mississippi, said that soon the East "would be so bald that every man would have to grow whiskers to hide its nakedness, but, thank God, the sky was safe." And John Muir, the Scottish-born explorer of Yosemite, wrote one day in his diary, about following a herd of grazing sheep through the valley, "Thousands of feet trampling leaves and flowers, but in this mighty wilderness they seem but a feeble band, and a thousand gardens will escape their blighting touch. They cannot hurt the trees, though some of the seedlings suffer, and should the woolly locusts be greatly multiplied, as on account of dollar value they are likely to be, then the forests, too, may in time be destroyed. Only the sky will then be safe." George Perkins Marsh, the first modern environmentalist, who knew over a century ago that cutting down forests was a disastrous idea, wrote, "The revolutions of the seasons, with their alternations of temperature, and of length of day and night, the climate of different zones, and the general condition and movements of the atmosphere and the seas, depend upon causes for the most part cosmical, and, of course, wholly beyond our control."

Even as it dawns on us what we have done, there will be plenty of opportunity to forget—at least, for a while—that anything has changed. It isn't natural beauty that is ended; in the same way that smog breeds spectacular sunsets, there may be new, unimagined beauties. What will change is the meaning that beauty carries, for when we look at a sunset we see, or think we see, many things beyond a particular arrangement of orange and purple and rose.

It is also true that this is not the first huge rupture in the globe's history. Some thirty times since the earth formed, "planetesimals" at least ten miles in diameter and travelling at sixty times the speed of sound have crashed into the earth, releasing perhaps a thousand times as much energy as would be liberated by the explosion of all present stocks of nuclear weapons; such events, some scientists say, may have destroyed up to ninety per

cent of all living organisms. Ice ages have come and gone. On a larger scale, the sun has steadily increased its brightness, growing nearly thirty per cent more luminous since life on earth began, forcing that life to keep forever scrambling to stay ahead (a race it will eventually lose, though not for some billions of years). Or consider an example more closely resembling the sharp divide we have now crossed. About two billion years ago, the spread of a particular kind of cyanobacteria caused, in short order, an increase in atmospheric oxygen from one part in a million to one part in five—that is, from one-ten-thousandth of a per cent to twenty-one per cent. Compared with that, the increase in carbon dioxide from two hundred and eighty to five hundred and sixty parts per million is as the hill behind my house to Annapurna. "This was by far the greatest pollution crisis the earth has ever endured," the microbiologist Lynn Margulis writes in "Microcosmos." Oxygen poisoned most microbial life, which, Margulis points out, "had no defense against this cataclysm except the standard way of DNA replication and duplication, gene transfer, and mutation." And, indeed, these adaptations produced the successful oxygen-utilizing life forms that now dominate the earth.

But each of these examples is different from what we now experience, for they were "natural," as opposed to man-made. A pint-size planet cracks into the earth; the ice advances and retreats; the sun, by the immutable laws of stars, burns brighter until its inevitable explosion; genetic mutation sets certain bacteria to spewing out oxygen until they dominate the planet—a strictly "natural" pollution.

One could argue that the current crisis, too, is "natural," since man is part of nature. This echoes the views of the early Greek philosophers who made no distinction between matter and consciousness: nature included everything. The British scientist James Lovelock wrote some years ago that "our species with its technology is simply an inevitable part of the natural scene"; that is, we are little more than mechanically advanced beavers. According to this view, to say that human beings have "ended" nature, or even damaged nature, makes no sense. But it is a debater's point, a semantic argument. When I say that we have ended

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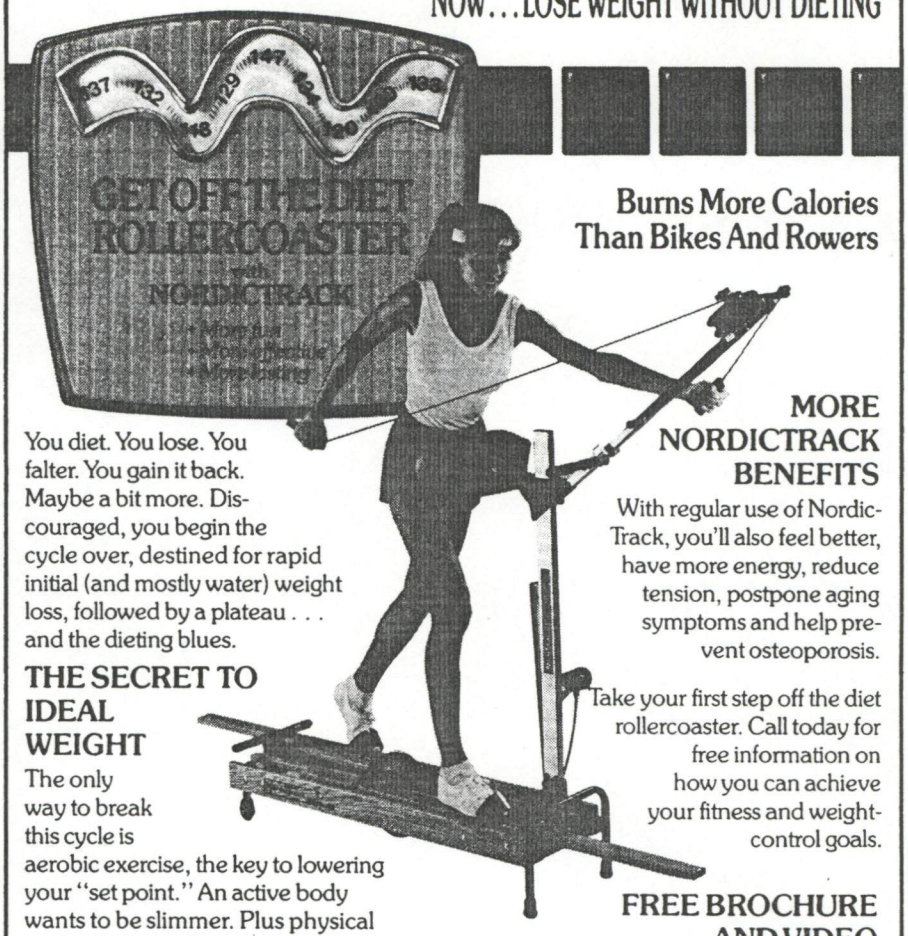

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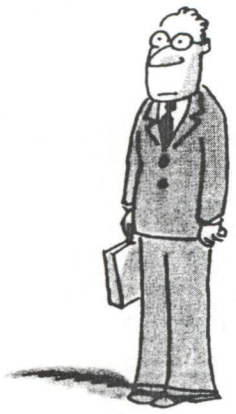

HARRY FENT, HUMAN BEING

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JAEGER

nature, I mean not that natural processes have ceased but that we have ended the thing that has—at least, in modern times—defined nature for us: its separation from human society.

That separation has been real. I sit writing here in my office. On the wall facing me is a shelf of reference books, and underneath them a typewriter and a computer. Visible through the window is a steep mountain, with nearly a mile of bare ridge and a pond almost at the peak. The mountain and the office are separate parts of my life; I do not think of them as connected. At night, it's dark out there; save for the street lamp by the lake, there's not a light for twenty miles to the west and thirty to the south. But in here the light shines. Its beams stretch a few yards into the night and then falter, turn to shadow and black. In the winter, it's cold out there, but in here the fire burns until near dawn, and when it dwindles the oil burner kicks in. What happens in here I control; what happens out there has always been the work of some independent force. It is this separate nature I am talking about when I use the word—"nature," if you like.

Scientists may argue that natural processes still rule, that the chemicals even now trapping the earth's reflected heat or eating away the ozone or acidifying the rain are proof that nature is still in charge—still our master. Some have talked about God as present in the interstices of the atom, or in the mysteries of quantum theory, or in the double helix of DNA and other bits of "information." To all but the few who really understand the math, though, this is a minor and secondhand comfort—an occult, esoteric knowledge. We draw our lessons from what we can see and feel and hear around us. The nature that matters is not the whirling fuzziness of electrons and quarks and neutrinos, which will continue unchanged; it is not the vast fields and fluxes that scientists can find with their telescopes. The nature that matters is the temperature, and the rain, and the leaves turning color on the maples, and the raccoons around the garbage can.

The invention of nuclear weapons may have marked the beginning of the end of nature; we possessed, finally, the ability to overmaster it, to leave an indelible imprint everywhere, all at once. "The nuclear peril is usually seen in isolation from the threats to other forms of life and their ecosystems, but in fact it should be seen as the very center of the ecological crisis—as the cloud-covered Everest of which the more immediate, visible kinds of harm to the environment are the mere foothills," Jonathan Schell wrote in "The Fate of the Earth." And, indeed, at the time he was writing—less than a decade ago—it was hard to conceive of a threat of the same magnitude. Global warming was one obscure theory among many; nuclear weapons were unique—and remain so, if only for the speed with which they work. But the nuclear dilemma is at least open to human reason. We can decide not to use the weapons—even to reduce and perhaps eliminate them. And the horrible power of these weapons, which has been amply demonstrated in Japan and on Bikini and under Nevada and many times in our imaginations, has led us fitfully in that hopeful direction.

By contrast, the various processes that lead to the end of nature have been essentially beyond human thought. Only a few people, for instance, knew that carbon dioxide would warm up the world, and for a long time they were unsuccessful in their efforts to alert the rest of us. Now it is too late—not too late (as I shall discuss) to ameliorate some of the changes, and so perhaps avoid the worst of their consequences. But a shift in weather is inevitable.

Just how inevitable we can see from the remedies that some scientists have proposed to save us—solutions that might bring things back to "normal." The most natural method anyone has suggested involves growing huge num-

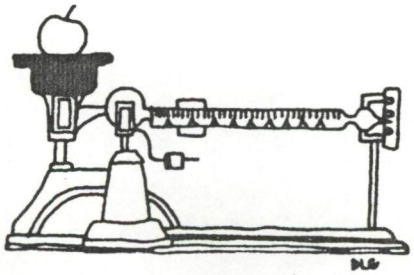
bers of trees to take carbon dioxide out of the air. Consider, for argument's sake, a new coal-fired electric-generating station that produces a thousand megawatts and operates at thirty-eight per cent thermal efficiency and seventy per cent availability. To counteract the carbon dioxide generated by that plant alone, you would need to cover the surrounding area to a radius of some fifteen miles with American sycamore trees—a fast-growing species—planted at four-foot intervals and "harvested" every four years. A government forestry expert told the Senate energy committee that, with genetic screening, spacing, thinning, pruning, weed control, fire and pest control, fertilization, and irrigation, net annual forest growth could be "very much higher than at present." Lay aside for the moment the inconvenient fact that enough forests to sop up merely the American output of carbon dioxide would cover fifty per cent more territory than we actually possess. Would this tree plantation be nature? A walk through an endless glade of evenly spaced sycamores, with the weed-control chopper hovering overhead and the quiet gurgle of the irrigation pipes, represents a fundamental break with our idea of the wild world.

Other proposals are even odder. The Columbia geochemist Wallace Broecker has speculated about the use of "a fleet of several hundred jumbo jets" to ferry thirty-five million tons of sulfur dioxide into the stratosphere annually, in order to reflect sunlight away from the earth. Other scientists recommend launching "giant orbiting satellites made of thin films," which could cast shadows on the earth, counteracting the greenhouse effect with a sort of venetian-blind effect. To deal with ozone depletion, Dr. Thomas Stix, a professor of physics at Princeton, suggests using a laser to scrub chlorofluorocarbons from the earth's atmosphere before they have a chance to reach the ozone layer. Dr. Stix calculates that an array of infrared lasers spaced around the world could blast apart a million tons of chlorofluorocarbons a year—a procedure he refers to as "atmospheric processing." Certain practical problems may hamper these various projects; Dr. Broecker, for instance, points out that injecting large quantities of sulfur dioxide into the atmosphere would increase acid rain and give a pale cast to the blue sky. Still, one or another of them just might work. And perhaps, as Dr. Broecker contends, "a rational society needs some sort of insurance policy on how to maintain a habitable planet." But even if they do work—even if the planet remains habitable—it will not be the same. The whitish afternoon sky blessed by the geometric edge of the satellite cloud will fade into a dusk crisscrossed by lasers. There is no way to reassemble nature.

THE passing of nature as we have known it, like the passing of any large idea, will have its recognizable effects both immediately and over time. In 1893, when Frederick Jackson Turner announced to the American Historical Association that the frontier was closed, no one was aware that the frontier had been the defining force in American life. But in its absence this was understood. One reason we pay so little close attention to the separate natural world around us is that it has always been there and we have presumed that it always would be. As it disappears, its primal importance will become clearer, in the same way that some people think they have put their parents out of their lives, until the day comes to bury them.

Above all else, the world displays a lovely order, an order comforting in its intricacy. And the most appealing part of this harmony, perhaps, is its permanence—the sense that we are part of something with roots stretching back nearly forever and branches reaching forward just as far. Purely human life provides only a partial fulfillment of this desire for a kind of immortality. But the earth and all its processes—the sun growing plants; flesh feeding on these plants; flesh decaying to nourish more plants, to name just one cycle—give us some sense of an enduring role.

John Muir expressed this sense of immortality beautifully. Born to a stern Calvinist father, who used a belt to help him memorize the Bible, Muir eventually escaped to the woods, travelling to the Yosemite Valley of California's Sierra Nevada. The journal of his first summer there is filled with a breathless joy at the grandeur around him. Again and again in that Sierra June—"the greatest of all the months of my life"—he uses the word "immortality," and he uses it in a specific way, designed to contrast with his father's grim and selfish religion. Time ceases to have its normal meaning in those hills: "Another glorious Sierra day in which one seems to be dissolved and absorbed and sent pulsing onward we know not where. Life seems neither long nor short, and we take no more heed to save time or make haste than do the trees and stars. This is true freedom, a good practical sort of immortality." To someone in a mood like this, space is no more of a limitation than time: "We are now in the mountains and they are in us . . . making every nerve quiver, filling every pore and cell of us. Our flesh-and-bone tabernacle seems transparent as glass to the beauty about us, as if truly an inseparable part of it, thrilling with the air and trees, streams and rocks, in the waves of the sun—a part of all nature, neither old nor young, sick nor well, but immortal."



Some dim recognition that God and nature are interwined has led us to pay at least lip service to the idea of "stewardship" of the land. If there is a God, He probably does want us to take good care of the planet, but He may want something even more radical. The Old Testament contains in the book of Job one of the most far-reaching defenses ever written of wilderness—of nature free from the hand of man. The argument gets at the heart of what the loss of nature will mean to us. Job is, of course, a just and prosperous man brought low. He refuses to curse God, but he does demand a meeting with Him and an explanation of his misfortune. Job refuses to accept the reasoning of his orthodox friends—that he has unknowingly sinned and is therefore being punished. Their view—that the earth revolves around man, and every consequence is explained by man's actions—doesn't satisfy Job, because he knows he is innocent.

Finally, God arrives, a voice from the whirlwind. But instead of engaging in deep metaphysical discussion He talks at some length about nature, about creation. "Where were you when I laid the earth's foundation?" He

asks. In an exquisite poem He lists His accomplishments, His pride in His creation always evident. Was Job there when He "put the sea behind closed doors"? Job was not; therefore, Job cannot hope to understand many mysteries, including why rain falls "on land where no one lives, to meet the needs of the lonely wastes and make grass sprout upon the ground."

"Behold now Behemoth," God roars. "He eateth grass as an ox. Lo now, his strength is in his loins. And his force is in the muscles of his belly. He moveth his tail like a cedar. . . . His bones are as tubes of brass. His limbs are like bars of iron. . . . Behold, if a river overflow he trembleth not. He is confident, though Jordan swell even to his mouth. Shall any take him when he is on the watch, or pierce through his nose with a snare?" The answer, clearly, is no: not all nature is ours to subdue.

Nature has provided a way for us to recognize God, and to talk about who He is—even, as in Job, a way for God to talk about who He is. So what will the end of nature as we have known it mean to our understanding of God and of man? For those of us who have tended to locate God in nature—who look upon spring, say, as a sign of His existence and a clue to His meaning—what does it mean that we have destroyed the old spring and replaced it with a new one, of our own devising? We as a race turn out to be stronger than we suspected—much stronger. In a sense, we turn out to be God's equal, or, at least, His rival—able to destroy creation. This idea has been building for a while. "We became less and less capable of seeing ourselves as small within creation, partly because we thought we could comprehend it statistically, but also because we were becoming creators, ourselves, of a mechanical creation by which we felt ourselves greatly magnified," the essayist Wendell Berry writes. "Why, after all, should one get excited about a mountain when one can see almost as far from the top of a building, much farther from an airplane, farther still from a space capsule?" And our nuclear weapons obviously created the possibility that we could exercise godlike powers. But the possibility is different from the fact. Though we seem to have recognized the implications of nuclear weapons and begun to back away from them, we have shown no such timidity in our wholesale alteration of nature. We are in charge now, like it or not. When God asks, as He does in Job, "Who shut in the sea with doors . . . and prescribed bounds for it?" and "Who can tilt the waterskins of the heavens?" we must now answer that it is us.

WITH this new power comes a deep sadness. I took a day's hike last fall, following the creek that runs by my door to the place where it crosses the main county road. It's a distance of maybe nine miles as the car flies, but rivers are far less efficient, and endlessly follow time-wasting, uneconomical meanders. The creek cuts some fancy figures, and so I was able to feel a bit exploratory—a budget Bob Marshall. In a strict sense, it wasn't much of an adventure. I stopped at the store for a liverwurst sandwich at lunchtime, the path was generally downhill, the temperature stuck at an equable fifty-five degrees, and since it was the week before the hunting season

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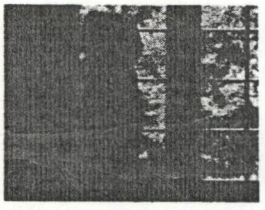

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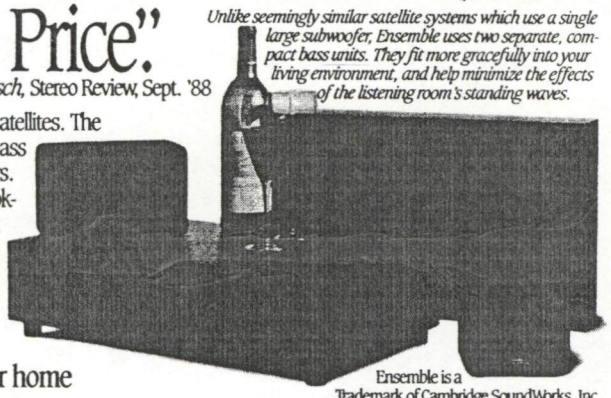

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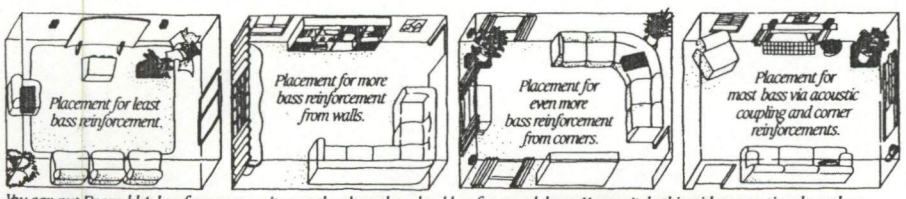

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opened I didn't have to sing as I walked. It isn't Yosemite, this small valley, but its beauties are absorbing, and one can say, with Muir on his mountaintop, "Up here all the world's prizes seem as nothing."

And so what if it isn't nature primeval? One of my neighbors has left several kitchen chairs along his stretch of the bank, spaced at fifty-yard intervals, for comfort in fishing. At one old homestead, a stone chimney stands at each end of a foundation now filled by a graceful birch. Near the one real waterfall, a lot of rusty pipe and collapsed concrete testifies to the mill that once stood there. But these aren't disturbing sights; they're almost comforting—reminders of the way that nature has endured and outlived and with dignity reclaimed so many schemes and disruptions of man. (A mile or so off the creek, there's a mine where a hundred and fifty years ago a visionary tried to extract pigment for paint and pack it out by mule and sledge. He rebuilt after a fire; finally, an avalanche convinced him. The path in is faint now, but his chimney, too, still stands, a small Angkor Wat of free enterprise.) Large sections of the area were once farmed; but the growing season is not much more than a hundred days in a good year, and the limits established by that higher authority were stronger than the (powerful) attempts of individual men to circumvent them, and so the farms returned to forest, with only a dump of ancient bottles or a section of stone wall as a memorial. These ruins are humbling sights, reminders of the negotiations with nature which have established the world as we know it.

Changing socks in front of the waterfall, I thought back to the spring of 1987, when a record snowfall melted in only a dozen or so warm April days. A little to the south, a swollen stream washed out a highway bridge, closing the New York Thruway for months. The creek became a river, and the waterfall, normally one of those diaphanous-veil affairs, turned into a cataract. It filled me with awe to stand there then, on the shaking ground, and think, This is what nature is capable of. But as I sat there this time, and thought about the dry summer we'd just come through, there was nothing awe-inspiring or instructive, or even lulling, in the fall of the water. It suddenly seemed less like a waterfall than like a spillway to accommodate the overflow of a reservoir. That didn't decrease its beauty, but it changed its meaning. It has begun, or will soon begin, to rain and snow when the chemicals we've injected into the atmosphere add up to rain or snow—when they make it hot enough over some tropical sea to form a cloud and send it this way. In one sense, I will have no more control over this process than I ever did. But the waterfall seemed different, and lonelier. Instead of a world where rain had an independent and mysterious existence, I was living in a world where rain was becoming a subset of human activity: a phenomenon like smog or commerce or the noise from the skidder towing logs on the nearby road—all things over which I had no control, either. The rain bore a brand: it was a steer, not a deer. And that was where the loneliness came from. There's nothing here except us.

At the same time that I felt lonely, though, I also felt crowded—without privacy. We go to the woods in part to escape. But now there is nothing except us, and so there is no escaping other people. As I walked in the autumn woods, I saw a lot of sick trees. With the conifers, I suspected acid rain. (At least I have the luxury of only suspecting; in too many places, they know.) And so who walked with me in the woods? Well, there were the presidents of the Midwestern utilities, who kept explaining why they had to burn coal to make electricity (cheaper, fiduciary responsibility, no *proof* it kills trees), and then there were the congressmen, who couldn't bring themselves to do anything about it (personally favor, but politics the art of compromise, very busy with the war on drugs), and before long the whole human race had arrived to explain its

aspirations. We like to drive, it said, air-conditioning is a necessity nowadays, let's go to the mall. Of course, the person I was fleeing most fearfully was myself, for I drive, and I'm burning a collapsed barn behind the house next week because it is much the cheapest way to deal with it, and I live on about four hundred times the money that Thoreau conclusively proved was enough, so I've done my share to take this independent, eternal world and turn it into a science-fair project.

Our local shopping mall has a club of people who go "mall-walking" every day. They circle the shopping center en masse—Caldor to Sears to J. C. Penney, circuit after circuit, with an occasional break to shop. This seems less absurd to me now than it did at first. I like to walk in the outdoors not solely because the air is cleaner but also because outdoors we venture into a sphere larger than we are. Mall-walking involves too many other people, and too many purely human sights, ever to be more than good-natured exercise. But now, out in the wild, the sunshine on one's shoulders is a reminder that man has cracked the ozone, that, thanks to us, the atmosphere absorbs where once it released. The greenhouse effect is a more apt name than those who coined it can have imagined. The carbon dioxide and the other trace gases act like the panes of glass of a greenhouse—the analogy is accurate. But it's more than that. We have built a greenhouse—a human creation—where once there bloomed a sweet and wild garden.

A HURRICANE draws its might from the heat transferred to the atmosphere when ocean water evaporates. The warmer the ocean's surface, and the deeper beneath the surface the warm water runs, the more powerful the hurricane. If the sea turns cold a few metres down, the winds will soon churn up that frigid water, and the storm will brake itself. But if the warm water runs deep—and in the tropics it may extend down a hundred and fifty metres or more—the hurricane will continue to build. Under present conditions—tropical ocean-surface temperatures of about 80° F.—Hurricane Gilbert, which formed off the Windward Islands in September of 1988, approached what Kerry Emanuel, a professor of meteorology at the Massachusetts Institute of Technology, has calculated to be the upper limit of intensity for a hurricane. The atmospheric pressure at its center dropped to about eight hundred and eighty-five millibars, and so its wind speed reached two hundred miles per hour. A hurricane can't get much worse than that—under present conditions. But a rise of three or four degrees in tropical sea-surface temperatures could raise the upper limit of hurricane strength. In the middle of these warmer storms, atmospheric pressure could fall to eight hundred millibars; as a result, the destructive potential of a hurricane would grow between forty and fifty per cent—a Gilbert and a half.

In the place of the old nature rears up a new "nature" of our own making. This new nature may not be predictably violent. It won't be predictably *anything*, and it will take us a long time to work out our relationship with it, if we ever do. The salient characteristic of this new nature is its unpredictability, just as the salient feature of the old nature was its utter dependabili-

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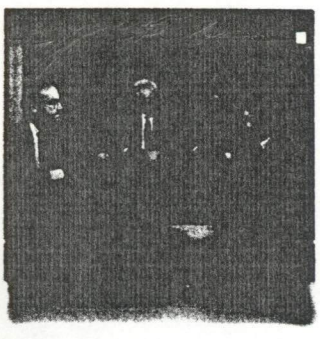

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ty. We are used to thinking of the manifestations of nature—rain or sunshine, say—as devious, hard to predict. And over short time spans and for particular places they are. But on a larger scale nature has been quite constant, and on a global scale it has been a model of reliability.

Virtually all settlement patterns testify to the dependability of nature. Every year during the late summer, the Nile overflows its banks—or did until the Aswan Dam was built. A pilot knows how the air will behave along his flight path—that a tropical air mass in summer over the Southeast will breed thunderstorms. Even extreme events, weather emergencies, have been fairly predictable. Engineers calculate the ability of every drainage and wall to withstand the "hundred-year storm." Every developer who builds a resort along the coast, every underwriter who insures a ship or a plane does so with a conscious dependence on the reliability of nature. And even more dependent are those of us who rely unconsciously on nature's past performance. The farmer has always watched for rain, and sometimes his crops have shrivelled, but those of us who do our harvesting at the supermarket never doubt that enough rain will fall on enough farms, and always it has.

It is this very predictability that has allowed most of us in the Western world to forget about nature, or to assign it a new role, as a place for withdrawing from the cares of the human world. In some parts of the globe, nature has been more capricious, withholding the rain one year or two, pouring it down by the lakeful the next, and in those places people think about the weather—about nature—more than the rest of us do. But even in Bangladesh, say, people have known that for the most part nature would support them. We have had what Loren Eiseley called "an old contract, an old promise . . . that nature, in degree, is steadfast and continuous." And this promise has enabled life to establish itself even in places we think of as harsh, since they have been harsh in a fairly dependable way. That promise was long ago broken for passenger pigeons, and for the salmon who ran into dams on the ancestral streams, and for peregrine falcons, whose eggshells were so weakened by DDT that they couldn't reproduce. But now it is broken for us, too—nature's lifetime warranty has expired.

Even if our knack for some sort of adaptation proves hardy—and, after all, boat people moving from Cambodia to Canada experience a much more severe climatic shift than anything the scientists predict—the stress will be continuous, unrelenting, because no one knows how all this will turn out. It will undoubtedly be worst for those already living on the edge, already subject to nature's whim—out on the floodplains of Bangladesh. But it will affect, at the very least, the mind of each of us. We are not necessarily doomed to suffer some cataclysm, but we can no longer count on not being so doomed. Professor Emanuel points out that there is no certainty that an increase in global warmth will push up tropical ocean temperatures and thus hurricane strength; neither is there any certainty that it won't. The uncertainty itself is the first cataclysm, and perhaps the most profound. When we can't depend on enough snow falling to fill the reservoirs that feed our faucets, or when we have to worry about too much of that water evaporating in the heat, then the weather report is going to be leading off the evening newscasts.

In the summer of 1988, while America sweltered, scientists on the staff of the Environmental Protection Agency were finishing up the most comprehensive assessment yet made of the possible effects of the climate change. Congress had requested the study two years earlier, and the E.P.A. had done its work diligently, studying four regions in great detail and compiling most of the available literature on the subject. The authors of the report, which was entitled "The Potential Effects of Global Climate Change on the United States," inserted several caveats. "We have no experience with the rapid warming . . . projected to occur during the next century," they wrote. "We cannot simulate in a laboratory what will happen over the entire North American continent." And they added, with ominous modesty, "The results are also inherently limited by our imaginations. Until a severe event occurs such as the drought of 1988, we fail to recognize the close links between our society, the environment, and climate. For example, in this report we did not analyze or anticipate the reductions in barge shipments due to lower river levels, the increases in forest fires due to dry conditions, or the impacts on ducks due to disappearing prairie potholes."

Let's look at that last, small item, "the impacts on ducks," for it sums up many of the lessons of this new, artificial nature. As the changes wrought by man have accelerated, so has the damage to other species. But there have been extensive efforts in recent years to save enough nature to accommodate at least some ducks (and bears and elk and eagles), and—to a certain degree, at least—these efforts have succeeded. In 1988, however, as ducks flew north in the summer they found very little water. Parts of North Dakota were ninety per cent dry, and one aerial survey of the Canadian prairie, Penny Ward Moser reported in *Sports Illustrated*, showed only seven of three hundred and thirty prairie potholes holding water. The potholes were a product of nature's slow pace: when the glaciers retreated from the northern Great Plains ten thousand years ago, they left pockmarks. Over the last hundred years or so, men have drained many of them, and the drought of 1988 emptied most of the rest. "The strongest of the early arrivals," Moser wrote of the ducks, "staked a claim, mated, and tried to raise a clutch in rapidly dwindling waters, surrounded by predators who congregated nearby, anticipating a summer-long feast." Some ducks took one look and decided to forget about mating; they spent the summer floating unproductively on larger lakes. Others flew farther north and arrived finally at usable habitat, but by then they were too protein-starved to produce eggs. Meanwhile, ducks that had found marshes to nest in, and had survived the lurking predators, began to contract botulism. In the warm and shallow water, it became an epidemic. Other ducks—many other ducks—died when the United States Department of Agriculture, in an attempt to aid drought-stricken farmers, released millions of acres of "set aside" and conservation land they had paid the farmers not to touch. As the tractors

roared through, nests and ducks were mowed and baled along with the hay. Millions of fish were dying, too, as temperatures soared in streams and lakes and as lowering water levels made fish more vulnerable to pesticides. Moser, on the farm in northern Illinois where she grew up, wrote, "We see no great blue herons in our streams this summer. There are barely any streams at all. The muskrats' underwater tunnels are high in the banks above the water. . . . Hanging over a culvert along the road, we watch some minnows wriggle over mud shallows looking for a deeper pool. Then the minnows reverse direction, pushing over the mud again, back to where they had been. *This is* the deeper pool."

Nature has always provided, as the Cape Cod essayist Robert Finch put it, the "deep, constant rhythms," even if we have come to think that we are independent of its pulses. We still rely on the earth's "basic integrity and equanimity" to give us a "safe and stable context," Finch writes, and, in particular, we rely on the seasons. "The recurring cycles of the year . . . are not simply entertaining phenomena, to be noted at our convenience and for our enjoyment," he writes, "but signs that the cosmos is still intact, that we remain included in something larger and more reliable than our own short-lived enthusiasms. It is for this that we need to know that insects will hibernate, that turtles and warblers will migrate and return, that the tide will retreat, the ice let go, the earth tilt back toward the sun, and the grass reawaken." Despite dozens of new ways to look at the world—the genetic, the microscopic, the chemical—we are still very much the same people who built Stonehenge to make sure each year that the sun really did begin its retreat, the same people who trembled at eclipses. We need to be able to worry about our human affairs secure in our knowledge of the eternal inhuman. The certainty of nature—that God's creation or Darwin's or whoever's will provide for us, bountifully, as it always has—is what frees us to be fully human, to be more than gatherers of food.

THE single most talked-about consequence of a global warming is probably the expected rise in sea level as a result of polar melting. For the last several thousand years, sea level has

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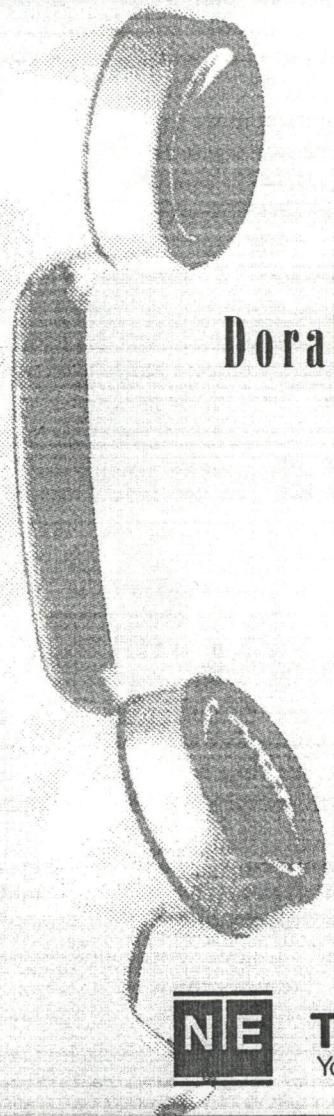

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been rising, but so slowly that it has almost been a constant. In consequence, people have extensively developed the coastlines. But a hundred and twenty thousand years ago, during the previous interglacial period, sea level was twenty feet above the current level; at the height of the last ice age, when much of the world's water was frozen at the poles, sea level was three hundred feet below what it is now. Scientists estimate that the world's remaining ice cover contains enough water so that if it should all melt it would raise sea level more than two hundred and fifty feet. This potential inundation is stored in the Greenland Ice Sheet (if it melts, it will raise the world's oceans twenty-three feet), the West Antarctic Ice Sheet (another twenty-three feet), and East Antarctica (more than two hundred feet), with a smaller amount —perhaps half a metre—in the planet's alpine glaciers. (Melting the ice currently over water, such as the sea ice of the Arctic Ocean, won't raise sea level, any more than a melting ice cube overflows a gin-and-tonic.) The East Antarctic is relatively safe; the direst fears of a rising sea came as the result of a 1968 study concluding that the Ross and Filchner-Ronne ice shelves, which support the West Antarctic Ice Sheet, could disintegrate within forty years. Subsequent investigations, however, seem to have demonstrated that such a disintegration would take at least two centuries, and probably more like five (though several investigators have speculated that it might become irreversible within the next century).

But the salvation of the West Antarctic does not mean the salvation of Bangladesh, or even of East Hampton. A number of other factors may raise sea level significantly. Glaciers bordering the Gulf of Alaska, for example, have been melting for decades, and constitute a source of fresh water about the size of the entire Mississippi River system. And even if nothing at all melted, the increased heat would raise sea level considerably. Warm water takes up more space than cold water; this thermal expansion, given a global temperature increase of between one and a half and five and a half degrees Celsius, should raise sea level a foot, according to James Hansen. It is by now widely accepted that sea level will rise significantly over the next decades. The E.P.A. has estimated that it will rise between five and seven feet by 2100, and speculated about worst-case scenarios that might lead to an eleven-foot rise; the National Academy of Sciences has been more conservative; other researchers have turned in even scarier numbers. Suffice it to say that included in the range of guesses of almost every panel and scientist studying the problem is an increase in global sea level of better than three feet over the next century.

That may not sound like very much, but it means that the sea would reach a height unprecedented in the history of civilization. The immediate effects of the swollen sea would be seen in a place like the Maldives. By most accounts, this archipelago of eleven hundred and ninety small islands about four hundred miles southwest of Sri Lanka is fairly paradisal. Its residents had never heard a gun fired in anger until last year, when a short-lived coup attempt was mounted by foreign mercenaries. They survived the downturn in the coir business (coir is an elastic fibre made from coconut husks); breadfruit and citron trees are abundant. But most of this happy nation rises only two metres above the Indian Ocean. If sea level were to rise one metre, storm surges would become an enormous, crippling danger; were it to rise two metres—well within the range of possibilities predicted by many studies—the country would all but disappear. In October of 1987, the Maldivian President, Maumoon Abdul Gayoom, went before the United Nations General Assembly. He described his country as "an endangered nation." The Maldivians, he pointed out, "did not contribute to the impending catastrophe . . . and alone we cannot save ourselves." A map drawn a hundred years from now may not show the Maldives at all, except as a danger to mariners.

Other nations, though not extinguished, would be very badly hurt. A two-metre rise in sea level would flood twenty per cent of the land in Bangladesh, much of which is built on the floodplains at the mouth of the Brahmaputra. In Egypt, such a rise would inundate less than one per cent of the land, but that area constitutes much of the Nile Delta, where most of the population lives. Nor is the danger only to the Third World. Several years ago, the E.P.A. distributed a worksheet to allow local governments to

calculate their future position vis-à-vis the salt water. In Sandy Hook, New Jersey, for instance, add thirteen inches to the projected increase in sea level to account for local geologic subsidence, for a net ocean rise, in the next hundred years, of four feet one inch. In Massachusetts, between three thousand and ten thousand acres of oceanfront land worth between three billion and ten billion dollars might disappear by 2025, and that figure does not include land lost to encroaching ponds and bogs as the rising sea lifts the water table. But storm surges would do the most dramatic damage: in Galveston, Texas, ninety-four per cent of the land is within the plain that would be flooded by the worst storms. Such surges are the reason that Holland built many of its protective dikes. The most extensive barriers went up after the winter of 1953, when a surge breached the existing dikes in eighty-nine places along the central delta, killing nearly two thousand people and tens of thousands of cattle. Afterward, the Dutch decided to spend more than three billion dollars building new defenses.

As the Dutch effort indicates, much can be done to defend against increases in sea level. The literature abounds with studies of how much it would cost to protect coastal areas. The trouble is, spending the money to protect the shoreline would lead to ecological costs harder to calculate but easy to understand. Coastal marshes or wetlands exist in a nearly unbroken chain along the Gulf and Atlantic Coasts of the United States. Protected from the waves of the ocean by barrier islands or peninsulas, they are part land and part water, and are home to an abundance of plants and animals. They are more biologically productive than either the ocean or the dry land, in part because tidal flows spread food and flush out waste; it is a cycle that encourages quick growth and rapid decay. These communities support an immense variety of birds, fish, shellfish, and plants. Early settlers (with noble exceptions, like William Bartram) thought coastal marshes "miasmal," and drained or filled many of them. In recent years, federal and state authorities have grudgingly begun to protect them. As King Canute demonstrated, however, the ocean disregards governments, and as its level rises the area of the wetlands will dwindle. This is not axiomatic: if the marsh has room and time enough

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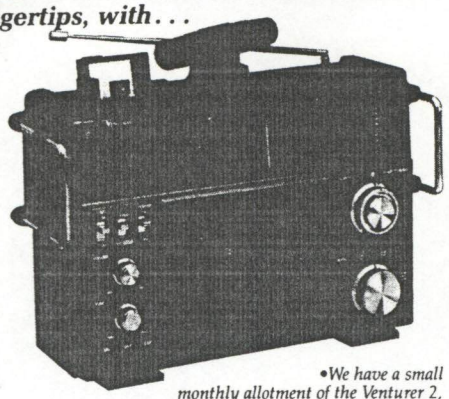

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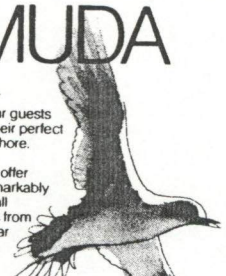

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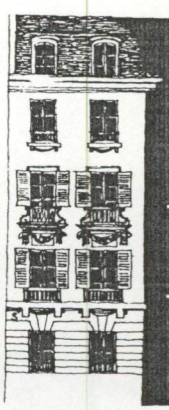

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to back up, it will, and the drowned wetland will be replaced by a new one. But, as another recent E.P.A. report pointed out, "in most areas . . . the slope above the marsh is steeper than the marsh; so a rise in sea level causes a net loss of marsh acreage." That is, in many cases the marsh will run into a cliff it can't climb. In a number of places, the cliffs will be man-made. If I have a house on Cape Cod, and my choice is to build a wall in front of it or let a marsh come in and colonize my basement, I will probably build the wall.

Should the ocean go up a metre, at least half the nation's coastal wetlands will be lost one way or another. "Most of today's wetland shorelines still would have wetlands," according to the E.P.A. report to Congress. "The strip would simply be narrower. By contrast, protecting all mainland areas would generally replace natural shorelines with bulkheads and levees." The relentlessly practical authors add that "this distinction is important because for many species of fish, the length of a wetland shoreline is more critical than the total area." It's also important if you are used to the idea of the ocean meeting the land with ease and grace instead of bumping into an endless concrete wall.

There are other reasons to fear a sea-level rise. In normal times, the water pouring out of a river pushes the ocean back. But in a drought the reduced flow creates a vacuum that the sea oozes in to fill. The "salt front" advances. In the drought of the nineteen-sixties, it nearly reached the point in the Delaware River where Philadelphia's water intake is located. During a drought, New York City must release vast quantities of water from its reservoirs on the upper Delaware to keep the salt front from creeping upriver. New Yorkers, however, continue to take showers and wash their hands. In the summer of 1985, city officials made up for the diminished flow from reservoirs by pumping water straight from the Hudson. This worked well—the water turned out to be considerably cleaner than many had expected—except that as the flow of the Hudson was reduced the salt front began to move up *that* river, and the town fathers of Poughkeepsie grew worried about *their* supply's getting salty. As the greenhouse warming kicks in, increased evaporation could steal from ten to twenty-four per cent of the water in New York's reservoirs, the E.P.A.'s 1988 report continues. In addition, a one-metre sea-level rise could push the salt front up past the city's water intake on the Hudson. In all, the report observes, "doubled carbon dioxide could produce a shortfall equal to twenty-eight to forty-two per cent of planned supply in the Hudson River Basin."

THE expected effects of sea-level rise typify the many other consequences of a global warming. On the one hand, they are of such magnitude that we can't grasp them. If there is significant polar melting, the earth's center of gravity will shift, tipping the globe in such a way that sea level might actually drop at Cape Horn and along the coast of Iceland. (I read this in the E.P.A. report and found that I didn't really know what it meant to tip the earth, though I was awed by the idea.) On the other hand, the changes ultimately acquire a quite personal dimension: Should I put a wall in front of my house? Does this taste salty to you? What's more, many of the various effects of the warming compound one another. If the weather grows hotter and I take more showers, more water must be diverted from the river, and the salt front moves upstream, and so on. The complications multiply almost endlessly (more air-conditioning means more power generated means more water sucked from the rivers to cool the generators means less water flowing downstream, et cetera ad infinitum). These aren't the simple complexities of, say, last summer, when everyone on the East Coast rushed to the beaches to escape the hot weather, only to discover a tide of syringes and fecal matter. These complexities are the result of throwing every single natural system into an uproar at the same time, so that none of nature's reliable compensations can be counted on. For example, at the same time that sea level is increasing, and the warmer air is gathering up more water vapor and presumably increasing the over-all precipitation, the temperature is continuing to go up. The result, the computer modellers say, will be greatly increased levels of evaporation; in many parts of the world, there will be a drier interior to complement the sodden coasts.

It's not simply a matter of heat. If the temperature rises, the number of

days with snow cover will likely fall. When the snow-melting season ends, more of the sun's energy is absorbed by the ground instead of being reflected back to space, and, as a result, the soil begins to dry out. In the greenhouse world, this seasonal change will begin earlier, because the snow will melt faster. In some areas, other weather changes may offset the evaporation. Roger Revelle, of the Scripps Institution, has estimated that flows in the Niger, the Senegal, the Volta, the Blue Nile, the Mekong, and the Brahmaputra would increase—probably with disastrous results in the last two cases—whereas flows might diminish in the Hwang Ho, in China; the Amu Darya and the Syr Darya, which run through the Soviet Union's principal agricultural areas; the Tigris-Euphrates system; and the Zambezi. The United States, as usual, has been most closely studied. America is blessed with ample water; on an average day, four trillion two hundred billion gallons of precipitation fall on the lower forty-eight states. Most of that water evaporates, leaving only about one trillion four hundred and thirty-five billion gallons a day, of which in 1985 only about three hundred and forty billion gallons a day were withdrawn for human use. It seems like more than enough. However, as anyone who has ever flown across the nation (and looked out the window) can attest, the water is not spread evenly. In its report to Congress, the E.P.A. notes that total water use exceeds average stream flow in twenty-four of the fifty-three Western water-resource regions, a difference made up by "mining" groundwater stocks and importing water. Much of the Colorado River's flow, for example, is dammed, diverted, and consumed by irrigation projects and by the millions upon millions of people living in places that would otherwise be too dry.

And matters may get worse. After studying the temperature and streamflow records, Revelle and the climatologist Paul Waggoner concluded that if a "conservative," two-degree-Celsius increase in temperature occurs, the virgin flow of the Colorado could fall by nearly a third; the same study predicts that if, as some of the computer models suggest, this temperature rise is accompanied by a ten-per-cent decrease in precipitation in the Southwest because of new weather patterns, runoff into the upper Colorado could

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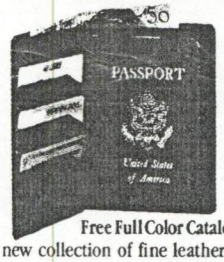

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fall by forty per cent. Even if rainfall went *up* ten per cent, the runoff would still drop by nearly twenty per cent. Across the West, the picture is similar: in the Missouri, Arkansas, lower-Colorado, and Rio Grande irrigation regions, supply could fall by more than half. In the Missouri, Rio Grande, and Colorado basins, the estimated water needs in the year 2000 could not be met by stream flows after the expected climatic changes. One model predicts a twenty-five-per-cent increase in the demand for irrigation water from the Ogallala Aquifer, the subterranean lake that irrigates the Great Plains and is already badly depleted.

A compelling question is what all this means for agriculture. The answer comes on several levels, the first being that of the individual plant. Quite apart from heat and drought, the simple increase of atmospheric carbon dioxide affects plants. Ninety per cent of the dry weight of a plant comes from the conversion of carbon dioxide into carbohydrates by photosynthesis. If nothing else limits a plant's growth—if it has plenty of sunshine, water, and nutrients—then increased carbon dioxide should increase the yield. And in ideal laboratory conditions this is what happens; as a result, some journalists have rhapsodized about "supercucumbers" and found other green linings to the cloud of greenhouse gases. But there are drawbacks. If some crops grow more quickly, farmers may need to buy more fertilizer, since leaves may become richer in carbon but poorer in nitrogen, reducing food quality not only for human beings but for nitrogen-craving insects, who may eat more leaf to get their fix. In the best case, direct effects of increased carbon dioxide on yield are expected to be small; the annual harvest of well-tended crops might rise about five per cent when the carbon-dioxide level reaches four hundred parts per million, all other things being equal.

But all other things won't be equal. All other things—moisture, temperature, growing season—will be different. It is an obvious point, but worth repeating: most of what we eat spends its growing life in the open air, "exposed," in the words of Paul Waggoner, "to the annual lottery of the weather." About fifty million acres of America's cropland and rangeland are irrigated, but even those fields depend on the weather over any long stretch. And we can't just stick the wheat crop under glass.

It is a tricky business trying to predict what changes in the weather will do to crops. A longer growing season —the period between killing frosts— surely helps; a lack of moisture surely hurts. If temperatures stay warm, plants grow nicely. If temperatures get really hot, they wither. (A long stretch above ninety-five degrees Fahrenheit, for instance, can sterilize corn.) The climate models are too crude to project with any precision what will happen in a given area, and too many variables make even the broadest predictions difficult. The severe droughts of the Dust Bowl years provide scant guidance: on the one hand, the technological revolution in agriculture has tripled yields since then, but on the other, as a government report notes, "the economic robustness associated with general multiple-enterprise farms has long since passed from the scene on any significant scale," and therefore "the current vulnerability of our agricultural system to climate change may be greater in some ways than in the past." Most of the experts have simply thrown up their hands. The best guesses seem to be that the northern reaches of the Soviet Union and Canada will be able to grow more food and the Great Plains of the United States less—not so little that America couldn't feed itself but enough below present production so that United States food exports, which earn the country some forty billion dollars in a good year, might fall by seventy per cent. "It has been suggested," Stephen Schneider told the Senate energy committee last year, "that a future with soil-moisture change . . . would translate to a loss of comparative advantage of United States agricultural products on the world market"—a sentence to make an economist shiver on an August day.

This sounds like somewhat comforting news—as if we would still have enough to eat—but when computers are modelling something as complex as all of agriculture the potential for error is enormous (or the potential for accuracy is small). The effect of the heat and drought of 1988 made liars of most of the computer models in just a few weeks. They had concluded that the

expected doubling of carbon dioxide in several decades might make the weather hot and dry enough to cut American corn and soybean yields as much as twenty-seven per cent, but in the summer of 1988, when the rains held off, the American corn crop fell thirty per cent—down by about two and a half billion bushels.

Even if, as seems likely, that heat wave had little to do with the greenhouse effect, we now have some idea what it will feel like once it is here. As of late August, the grain stored around the world amounted to only about two hundred and eighteen million metric tons—enough to last forty-seven days, and the lowest level since 1973. Worldwide consumption of grain outpaced worldwide production by sixty million metric tons last year. You can live with a budget deficit for quite a while, but when the food runs out there's no central bank to mint some more.

The thing to remember is that all these changes may be happening at once. It's hotter, and it's drier, and sea level is rising as fast as food prices, and hurricanes are strengthening, and so on. And not least is the simple fact of daily life in a hotter climate. The American summer of 1988, when no one talked about anything but the heat and how soon it would end, was only a degree or two warmer, on average, than what we were used to. But the models predict that summers could eventually be five or six or seven degrees warmer than the old "normal." Science has yet to devise a way of determining what percentage of people feel like human beings on any given August afternoon, or the number of work hours lost to the third cold bath of the day—or, for that matter, the loss of wit and civility in a population concerned mainly with keeping its shirts dry. These are important matters, and a future full of summers like that one is a grim prospect. Summer will come to mean something different—not the carefree season anymore but a time to grit one's teeth and get through. To anyone who lived through the 1988 heat it seems unlikely that people will simply get used to it.

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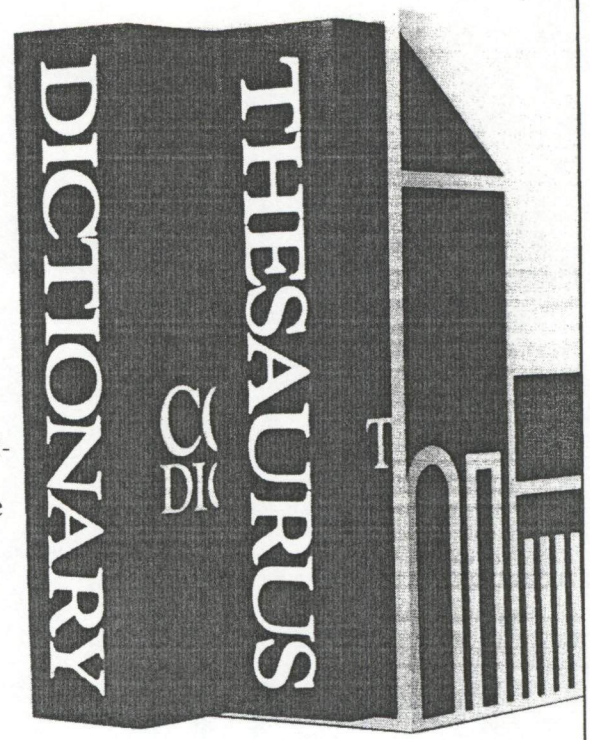

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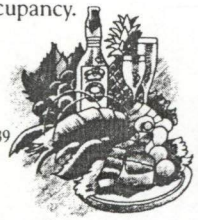

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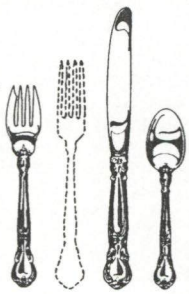

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preterm births and perinatal deaths both rise. Mortality from heart disease goes up during heat waves, and emphysema gets worse. If, the E.P.A. notes, in its 1988 report to Congress, "climate change encourages a transition from forest to grassland in some areas, grass pollens could increase," worsening hay fever and asthma. "A variety of other U.S. diseases indicate a sensitivity to changes in weather," the report continues. "Higher humidity may increase the incidence and severity of fungal skin diseases (such as ringworm and athlete's foot), and yeast infections (candidiasis). Studies on soldiers stationed in Vietnam during the war indicated that outpatient visits for skin diseases (the largest single cause of outpatient visits) were directly correlated to increases in humidity."

That last sentence suggests that a useful place to look for information about American weather might be Vietnam. There is nothing wrong with the Vietnamese climate—it is not "better" or "worse" than the various American climates, or the weather in Britain, or the cold of Canada. And people have been able to move back and forth between all these zones, adapting to conditions. In fact, we often want to —a change of climate is perhaps the single biggest inducement to travel. But now the climate is travelling. A recent United Nations study estimates that sometime in the next century the climate of Finland will have become similar to that of northern Germany, that of southern Saskatchewan to northern Nebraska, of the Leningrad region to the western Ukraine, of the central Urals to central Norway, of Hokkaido to northern Honshu, and of Iceland to northeast Scotland. If we felt like keeping the weather we're accustomed to, it's we who would have to move, travelling north ahead of the heat.

The list of miscellaneous circumstances that might result from changes in the atmosphere looks to be infinite. In New York City, the heat of the summer of 1988 softened asphalt and caused thousands of "hummocks"—potholes in reverse—in the streets. "When it's over ninety degrees for a prolonged period of time, the problem is virtually out of control," Lucius Riccio, of the New York City Bureau of Highway Operations, told the *Times*. Steel expansion joints buckled along Interstate 66 around Washington, D.C., during the heat wave, and a hundred and sixty people were injured when a train derailed in Montana, apparently because the heat warped the rails. Coupled with the physical predictions are endless political and financial conjectures. Francis Bretherton, of the National Center for Atmospheric Research, told *Time* that if the Great Plains became a dust bowl and people followed the seasonable temperatures north, Canada might replace the United States as the Western superpower.

This game swings from the specific to the wildly speculative. There is no easy way to say that something can't happen or is unlikely to happen; forecasts have to be based on the past, and there is no longer a relevant past. Jesse Ausubel, the director of programs at the National Academy of Engineers, told *Fortune* that it "may become difficult to find a site for a dam or an airport or a public transportation system or anything designed to last thirty to forty years," and asked, "What do you do when the past is no longer a guide to the future?" We are left with a vast collection of "mights," and only one certainty: we have changed the world, and therefore some of the "mights" are inevitable. I find myself thinking often of some purple-martin chicks that Penny Moser found "cooked to death" near her Illinois farm in 1988's heat. This was an actual event and also a metaphor. The heat will cook the eggs of birds, and that destruction—and the hurricanes and the rising sea and the dying forests —will rob us of our sense of security. That the temperature had never reached a hundred degrees at the airport in Glens Falls, the city nearest my home, made it a decent bet that it never would. And then, in July of 1988, it did. There is no good reason anymore to say that it won't reach a hundred and ten degrees. The old planet is a different planet. There is no reason to feel secure, because there is no reason to be secure.

LAST summer, I paddled across a northern Adirondack lake with a state biologist to visit an eagle's nest. Thirty years before, in an effort to curb black flies, communities in this area put big blocks of DDT in the streams. The black flies survived (they hung in clouds around us the whole morning), but the eagles, among others, didn't.

The chemical thinned the shells of their eggs; when the mother eagles sat on the eggs, the shells collapsed. Finally, last year, three pairs of eagles returned to the Adirondacks and built nests. We sat in the canoe and watched a big eagle circle above us with patient irritation, head ruffled. His mate was on the nest, and we were too close. He swooped nearby; we backed off; he rose with a beat or two of his six-foot wingspan and flew for the nest. When he got there, he flared his wings, stalled, and dropped softly down.

Had Rachel Carson not written when she did about the dangers of DDT, it might well have been too late by the time anyone cared about what was happening. She pointed out the problem; she offered a solution; the world shifted course. That is how this discussion should end, too. At this writing, the greenhouse effect shows every sign of becoming an important political issue. President George Bush has called for an international scientific workshop on the subject; there is talk of drawing up an international treaty on climate change modelled on the recent international accords to phase out production of chlorofluorocarbons. It all sounds promisingly rational. We ought to come up with a good practical response, a plan, a series of steps, a seven-point proposal to offset the greenhouse effect. That is our reflex. The minute the scientists at the June, 1988, congressional hearings finished explaining that we were heating up the earth, senators began talking about nuclear power; it was literally their first reaction. Senator Frank Murkowski, of Alaska, asked, "Is it indeed a reality that we must look more aggressively to nuclear as a release? Because I don't see the public demanding any reduction in the power requirements that our air-conditioners run off of, everything else that we enjoy." Not even the senator from Alaska can imagine life without air-conditioning, so we must come up with some solution, and fast. But is nuclear power a solution? Lay aside the questions of whether it's safe and what we will do with the resulting waste (though it is a sign of the depth of our addiction that we would be willing to lay aside such considerations). Nuclear energy is, at the moment and for the foreseeable future, useful for generating electricity but not for, say, powering my Honda. We may well need to

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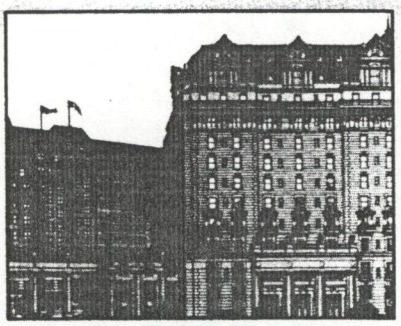

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swallow our fears about safety and build more reactors, but doing so won't make everything all right. Returning to the same mix of natural gas and coal that America used in 1973 could save as much carbon dioxide as expanding nuclear power fifty per cent. And we have no spare decades in which to build more Shorehams and Seabrooks; putting off the solution twenty or thirty or forty years would give us thirty or forty or sixty more parts per million of carbon dioxide.

But what about increasing efficiency —what about conservation? There is —no question—waste, even sixteen years after the energy crisis. For example, most of the electricity consumed by industry is used to drive motors; companies, anticipating expansion, tend to buy larger motors than they need; however, large motors are inefficient when they run at less than full speed. The latest edition of the *World Resources* yearbook estimates that if every industrial motor in the United States were to be equipped with available speed-control technology America's total electricity consumption would fall seven per cent. We must end waste, the sooner the better. But will this kind of action *solve* the problem? Consider a few numbers supplied by Irving Mintzer, of the World Resources Institute. He describes a "base case" scenario that "reflects conventional wisdom in its assumptions about technological change, economic growth, and the evolution of the global energy system." In this model, nations do not enact policies to slow carbon-dioxide emissions, nor do they provide more than minimal support for increased energy efficiency and solar research and development, though they do slow the rate of chlorofluorocarbon production. The result is an average global warming of up to 4.7°F. by the year 2000, and of up to 8.5°F. by 2030. This, Mintzer says, "is by no means the worst possible outcome." If the use of coal and synthetic fuels is encouraged, and tropical deforestation continues to increase, the planet would be doomed to an increase of up to 12.6°F. by 2030, and, by 2075, to a nearly thirty-degree jump—a level with implications too sci-fi for us to imagine. The good news, such as it is, concerns Mintzer's "slow buildup scenario." In this one, strong international efforts to reduce greenhouse-gas emissions "eventually stabilize the atmosphere's composition." Coal, gas, and oil prices are markedly increased, per-capita energy use declines in industrialized countries, and governments actively pursue the development of solar energy. The world embarks on "massive" reforestation efforts. And so on. If all these heroic efforts had begun in 1980, by 2075 we would experience a warming of between 2.5°F. and 7.6°F., which is still "greater than any experienced during recorded human history."

Carbon dioxide and other greenhouse gases come from everywhere, so the situation they create can be fixed only by fixing everything. Small substitutions and quick fixes are not the answer. One common suggestion is to replace much of the coal and oil we burn with methane, since it produces considerably less carbon dioxide. But, as I have noted, any methane that escapes unburned into the atmosphere traps solar radiation twenty times as efficiently as carbon dioxide does. And methane does leak—from wells, from pipelines, from appliances; some estimates suggest that as much as three per cent of the natural gas tapped in this country escapes unburned. So converting from oil to natural gas might make the situation worse. The size and complexity of the industrial system we have built makes even small course corrections physically difficult.

Not only is that system huge but the trend toward growth is incredibly powerful. At the simplest level—population—the increase continues, if not unabated, then only slightly abated. In some of the developing countries, thirty-seven per cent of the population is under fifteen years of age; in Africa, the figure is forty-five per cent. Without a static population, even the most immediate and obvious goals, like slowing deforestation or reducing fossil-fuel use, seem far-fetched. Over the last century, a human life has become a machine for burning petroleum. At least in the West, the system that produces excess carbon dioxide is not only huge and growing but also psychologically all-encompassing. It makes no sense to talk about cars and power plants and so on as if they were something apart from our lives—they *are* our lives. Moreover, for any program to be a success we must act not

only as individuals and as nations but as a community of nations. The trouble is, though, that some countries may perceive themselves to be potential winners in a climatic change. The Russians may decide that the chance of increased harvests from a longer growing season is worth the risk of global warming. And the United States, the Soviet Union, and China own about two-thirds of the world's coal reserves, so any one of them can scuttle progress. The possibilities of other divisions—rich nations versus poor nations, say—are large. Every country has its own forms of despoliation to protect; the Canadians, for instance, who complain loudly about their position as helpless victims of American acid rain, are cutting down the virgin forests of British Columbia at an almost Brazilian pace. And the fact that decisions must be made now for the decades ahead means that, in the words of Richard Benedick, our Deputy Assistant Secretary of State for Environment, Health, and Natural Resources, "somehow, political leaders and government processes and budget-makers must accustom themselves to a new way of thinking." Of all the quixotic ideas discussed here, that may top the list.

The greenhouse effect is often compared to the destruction of the ozone layer, another example of atmospheric pollution with global implications. But the destruction of the ozone layer can and likely will be solved by our ceasing to produce the chemicals currently destroying it. Though this step won't end the problem overnight, it will take care of it eventually. And, though the necessary international negotiations may be complex, steps like this are easy enough so that they will certainly be taken. Essentially, it's like controlling DDT. The problem of global warming, however, does not yield to the same sort of solution. With aggressive action—as Mintzer's numbers indicate—we can "stabilize" the situation at a level that is only mildly horrific, but we cannot solve it.

This is not to say that we should not act. We must act, and in every way possible, and immediately. We stand at the end of an era—the hundred years' binge of oil, gas, and coal which has given us both the comforts and the predicament of the moment. Even those countries which wouldn't object to a degree or two of warming for a longer growing season can't endure endless heating. The choice of doing nothing—of continuing to burn ever more oil and gas and coal—is not a choice. It will lead us, if not straight to hell, then straight to a place with a comparable temperature. But even the scientists calling most vociferously for controls on emissions say they are doing so in order to slow down the warming so that we can adapt to it. That adaptation is all that remains to be discussed.

ADJUSTMENT to the greenhouse world will not be easy; our addiction to oil is deep. Our every comfort—especially the freedom from hard labor, for those of us who enjoy such freedom—depends on fossil fuels. They allowed us to dominate the earth, instead of letting the earth dominate us. Our impulse will be to adapt not ourselves but the earth—to figure out a new way to continue our domination, and hence our accustomed life styles, our hopes for our children. This defiance is our reflex. Our impulse will be to defy the doomsayers and press ahead into a new world.

The futurist Julian Simon has infuriated environmentalists by predicting that before we ran out of anything essential, scientists would discover new ways to produce it; if we started to run out of copper, say, we would find out how to make it from other metals. In a 1981 book called "The Ultimate Resource," he writes that with knowledge, imagination, and enterprise "we can manipulate the elements in such fashion that we can have all the mineral raw materials that we need and desire at prices ever smaller relative to other prices and to our total incomes. In short, our cornucopia is the human mind and heart."

This is not a scientific treatise—Simon has not discovered how to produce copper from other metals. It is, despite its reliance on "long-run economic indicators" and such, a religious argument, an article of faith. "The main fuel to speed our progress is our stock of knowledge, and the brake is our lack of imagination," he writes. "To have more children grow up is also to have more people who can find ways to avert catastrophe." The religiosity of this view can be seen as well in books like "The Hopeful Future," of 1983, whose author, G. Harry Stine, argues that to make predictions based on current rates of growth and prog-

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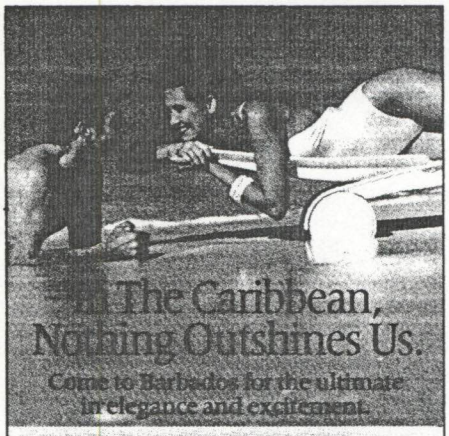

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ress is absurd. Even a curve that shows the rate of human progress as increasing from its present mind-boggling pace is too conservative. Only "Curve E," a "cubic curve that continues to turn upward ever more steeply with no limit in sight," makes sense. "It means that we can expect eight times as much progress in the next fifty years as we have seen in the past fifty," he says. This is not, strictly speaking, blind faith; the optimists can explain their reasoning. But it is faith, and it comes with other religious trappings —a dark view of people who think differently, for instance. ("Some of the 'futurists' making 'downside' forecasts don't like people. That means they don't like themselves either," Stine chides.) And there is a vision of a not too distant utopia. In the twenty-first century, Stine writes, enormous orbiting satellites will beam down "enough energy for everybody to do everything."

I am not dismissing the futurists. On the contrary, I think it possible that they are right: we can keep progressing, even in the teeth of the greenhouse effect. We will invent new tools, new technologies, to keep ourselves alive on the planet. We will figure out ways to extend our control so far that not even the rogue nature we have inadvertently created in our last century of progress will escape our domination. I can imagine scenarios—a nuclear war, for instance—that would cancel this future. But my guess is that the defiant optimists are likely correct in their assertion that we can have a "macromanaged" world—one that may well allow us to continue our ways of life even in the face of the coming heat. People with sincere and "progressive" ideas about man's future profess their hope for such a world. Buckminster Fuller is probably the great example. He was not an enemy of the environment; his geodesic domes, for instance, are as stable as conventional buildings, at about three per cent of the weight. Were we all to live in them, there would be a lot more forests standing.

He was not an enemy of the environment, but he was a champion of man. "We have to deal with our spaceship, Earth, as a machine, which is what it is," he wrote in "Approaching the Benign Environment." I doubt whether Fuller would have viewed the end of nature with much trepidation, for he never believed that we would or should stay long in the surroundings we had grown accustomed to. Instead, we were like a chick in a shell. This shell had just enough food in it—enough coal and oil and oxygen and whatever—to allow us to develop to a certain point. "But then, by design, the nutriment is exhausted just at the time when the chick is large enough to be able to locomote on its own legs," he wrote. "And so as the chick pecks at the shell seeking more nutriment it inadvertently breaks open the shell." The analogy is somewhat selfish—that there are other species in the shell with us seems not to have crossed his mind—but it may well be correct.

As a mild example of our hubris, consider a recent book: "Gaia—An Atlas of Planet Management." Despite this title, it does not, I think, reflect fully the Gaia hypothesis, which was first outlined by James Lovelock in the nineteen-seventies; namely, that the earth is a self-sustaining, self-regulating organism. Instead, it argues that man should take ever more control of the planet. Its editor, Norman Myers, seems almost thrilled by the current state of affairs. The approaching crises represent "our final evolutionary examination." We must rise to the occasion, pass the test. And we will: "We are grown up. We have acquired the power of life and death for our planet and most of its inhabitants. . . . Our 'satellite vision' means that all the planet's resources—soils, forests, rivers, oceans, minerals—can be not only mapped in fine detail, but vetted for pollution, erosion, or drought; for changes in albedo or humidity . . . for movements of shoaling fish and migratory creatures." We can process this data at high speed in our computers; we can communicate it around the world instantly. And we can act on it. "With the power of life in our hands, we could, for instance, make forests spring up on bare lands, safeguard species against the pressures for extinction." It is time for us, "as incipient planet managers," to "use this power and use it well," Myers goes on. "The ancient Greeks, the Renaissance communities, the founders of America, the Victorians, enjoyed no such challenge as this. What a time to be alive!" The physician Lewis Thomas is

quoted as saying that if we succeed "we could become a sort of collective mind for the earth."

This is the defiant reflex, cloaked in a filmy veil of New Age ecological thinking. Many of the proposals of the planet managers are sound—the usual suggestions of environmentalists. In the world we have created, they may offer us our only chance. But the planet managers have respect mostly for man: they understand that the current methods of domination will overheat the planet, but they have new and improved methods. In their forests of the future, cloned Douglas firs and American sycamores will "sprout like mushrooms," growing straighter, producing "denser wood." Almost all wildlife can be "harvested" from preserves, so that "conservation and profit can go hand-in-hand." Even at its most far-reaching, though, "macromanagement" remains a fairly crude enterprise. You may be able to keep track of fish by satellite, but they are still wild creatures, growing at their own pace. The next step—the step we stand about to take—is much more radical.

THE first time I gave much thought to biotechnology, I was a young reporter covering the weekly meetings of the city council of Cambridge, Massachusetts. For several years, the councillors debated how to regulate the genetic-engineering work then under way at Harvard and M.I.T. Week after week, Nobel Prize winners and brilliant young researchers would arrive at the meetings to answer questions; their biggest doubter was Alfred E. Vellucci, the councillor from Italian and Portuguese East Cambridge, who would long ago have won a Nobel himself if only they were awarded for local politics. Gifted with a strong imagination, Vellucci conjured up countless possible ways for "these bugs," the reprogrammed organisms, to be accidentally released. Could they escape through the sewers? The air-conditioning? On the soles of people's shoes? Eventually, and over the protests of the universities, the city enacted fairly strict regulations governing "containment"—the thickness of laboratory doors, and so on. I remember thinking that gene-splicing was something like nuclear power—potentially useful, albeit risky. It didn't occur to me then

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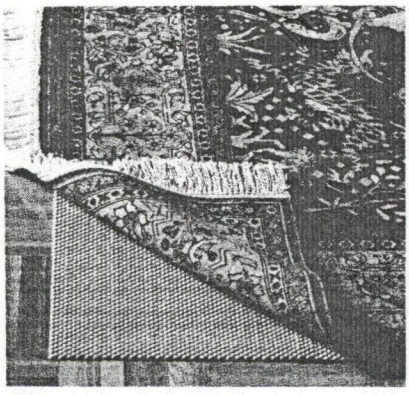

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to think much more deeply about it.

But genetic engineering is the first way to create new life. It is a staggering idea—"the second big bang," as one biologist put it. Just in time—just as the clouds of carbon dioxide threaten to heat the atmosphere—we are figuring out a new method of domination, a method more thorough, and therefore more promising, than burning coal and oil and natural gas. It is the method that offers us the most hope of continuing our way of life, our economic growth. It promises crops that need little water and can survive the heat; it promises cures for the new ailments we are creating as well as the old ones we have yet to defeat; it promises a way to survive in almost any environment we may create.

And for this reason it is without a doubt the most important scientific advance ever, in conceptual and moral terms. When I say "moral," I am not thinking primarily of the uses to which such technology might be put—eugenics, for instance. I am thinking of the very fact of the technology. The environmental lobbyist Jeremy Rifkin, who has emerged as one of the few vigorous opponents of genetic engineering, says that for thousands of years human beings have lived "pyrotechnically," burning, melting, mixing inanimate materials—coal, say, or iron. We have worked from the outside in, to alter our environment. Now we are starting to work from the inside out, and that changes everything. Everything except the driving force, the endless desire to master our planet. The British writer Brian Stableford declares in his celebratory book "Future Man" that genetic engineering "will eventually enable us to turn the working of all living things on earth—the entire biosphere—to the particular advantage of our own species." No clearer and crisper definition exists of what I have been calling "defiance."

Watson and Crick described the double helix of DNA in 1953. Just twenty years later, Stanley Cohen, of Stanford, and Herbert Boyer, of the University of California at San Francisco, took two unrelated organisms and cut out a piece of DNA from each. They knit the pieces together, and when they were done they had a new form of life, a kind of life that had not existed five minutes before. In 1981, scientists from the University of Ohio and from Jackson Laboratory, in Bar Harbor, Maine, transferred a gene that controlled the manufacture of part of the hemoglobin in rabbits to a mouse embryo, which they brought to term. The mouse was not exactly a mouse; it had a functioning rabbit gene, which it passed on to subsequent generations. This proof of the possibility of blends between unrelated species was soon followed by others. English researchers crossed a goat and a sheep, two animals that wouldn't dream of mating in the barnyard (or, if they did—for dreams are widespread—nothing would come of it). At the University of Pennsylvania, biologists managed to insert human growth-hormone genes in the fetus of a mouse. After it was born, the mouse grew twice as fast as other mice and to twice their size. Having passed the gene on to its offspring, it made forever moot the question "Are you a man or a mouse?" These mice are both, and neither.

By the end of 1988, according to a tally in the *Times*, there were more than a thousand different strains of such "transgenic" mice, as well as twelve breeds of pig and several varieties of rabbits and fish. In the spring of that year, two Harvard researchers announced the creation of a mouse that was genetically altered to develop cancer, so that oncologists could use it for studying new treatments. Unlike the earlier inventions, this mouse had commercial possibilities and was awarded the nation's first animal patent. The patent was licensed to Du Pont, and the mice will go on sale this fall, for fifty dollars apiece.

Even these mice, though, will be confined to laboratories (until they escape). A bigger barrier probably fell in April of 1987, when workers from a company called Advanced Genetic Sciences released the first genetically altered bacteria to the great outdoors—in a strawberry field in Brentwood, California. Trademarked Frostban, the bacteria —*Pseudomonas syringae* and *Pseudomonas fluorescens*—lacked an "ice-nucleating gene" in their DNA and were designed to prevent crop losses from frost damage. Environmental activists had ripped up many of the strawberry plants in an attempt to delay the test, but it was an empty gesture. A few days later, Steven Lin-

dow, the man who discovered the operative gene, sprayed Frostban bacteria on a field of potato plants in Tule Lake, California, without any interference.

The pace of this revolution keeps speeding up. Genetically "improved" trees, for instance, already exist. A Seattle company selects "élite" redwoods from its wild stands, on the basis of such qualities as trunk straightness, height, "specific gravity" of the wood, and "proper branch drop." Then it clones the trees and plants the seedlings; eventually, gnarly, crooked trees will be gone from its stands. Classical methods of improving seeds do not "adequately satisfy the criteria of the rapid availability of trees of superior quality," according to a 1982 report by Congress's Office of Technology Assessment. Christmas-tree growers are now attempting to clone trees with branches that rise at the proper forty-five-degree angle and carry thick needles that "do not fall off to litter the living room floor." A company called Calgene has isolated a gene that gives tobacco plants some resistance to the herbicide glyphosate. The herbicide works by blocking a pathway in plants that synthesizes aromatic amino acids; once the tobacco plants have been genetically retuned, however, you can spray the herbicide on the surrounding weeds without hurting the tobacco.

The future—the fairly near future—holds much more, at least according to the most fanciful accounts. In his book, Brian Stableford promises that the "battery chickens" of tomorrow will look very different from the birds of the moment, and in fact the accompanying illustration shows them looking rather like hunks of flesh. This is because we may be able to design chickens without the unnecessary heads, wings, and tails. "Nutrients would be pumped in and wastes pumped out through tubes connected to the body," Stableford says. Perhaps we could "grow" lamb chops on an "infinite production line, with red meat and fat attached to an ever-elongating spine of bone." Eventually, all plants might "become unnecessary," having been replaced by artificial leaves that would waste none of the sunlight they received on such luxuries as roots but instead would employ "the energy they trap to make things for us to use."

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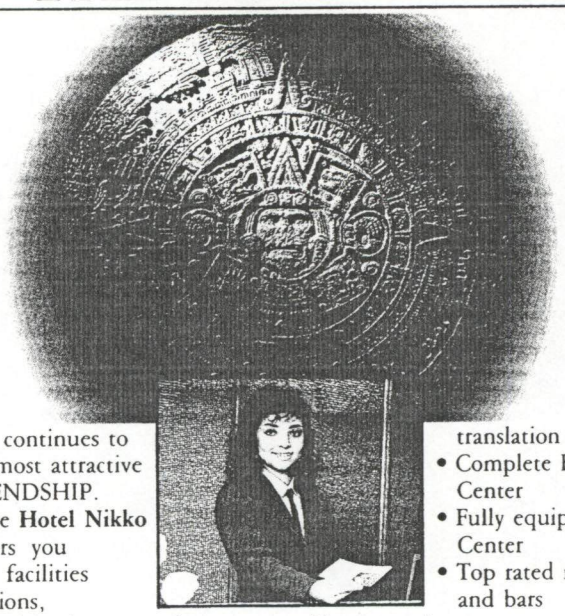

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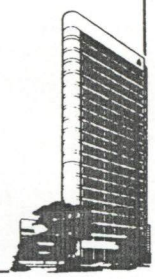

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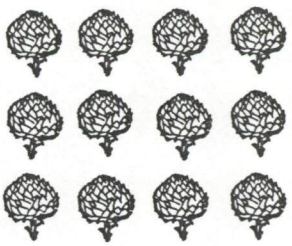

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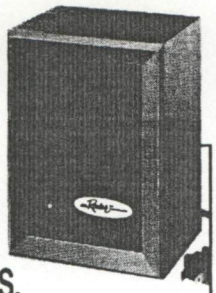

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night vision, or sonar (although, Stableford says, "this would involve whole new anatomical structures being added to the head"), or double-glazed eyes for living in space, or the "very minor modification" that would allow us to digest cellulose? These developments, though in the future (and farther in the future, I would guess, than these authors predict), are not conceptually different from what we have begun to do in the last twenty years, and what we have started to do in a large way in the last two years. The line is not in the distance; the line is here and now, and we shall very soon be on the other side, if we're not there already. And on the other side of the line is the second end of nature.

Some people tend not to worry very much about genetic engineering or other such developments, because they think of them as extensions of traditional practices—selective breeding, for example. But nature put definite limits on such activities. Mendel could cross two peas, but he couldn't cross a pea with a pine, much less with a pig, much less with a person. We could pen up chickens in batteries, but they still had heads. Our understanding of the natural limits helped define nature in our minds. Such notions will quickly become quaint. The idea that nature—that *anything*—could be defined will soon be outdated. Because anything can be changed. A rabbit may be a rabbit for the moment, but tomorrow "rabbit" will have no meaning. "Rabbit" will be a few strands of genetic code, no more important than a set of plans for a 1940 Ford. Why not make a rabbit more like a dog, or a duck? Whatever suits us. In such a world, nothing will be impossible—including, perhaps, immortality. Why die? (Why age?) Whether eternal life will have any meaning is another matter. "Eventually," Stableford says, "there may well be a complete breakdown in the distinction between the living and the non-living: the boundary between the two will be blurred and filled in by systems which involve both the machinery of life and the machinery of metal, plastic, and glass."

All this is speculation, certainly. No one can say with any exactness what will result from a development as awesome as the cracking of the gene. But if that technology falters some other may emerge. It is the logical outcome of our belief that we must forever dominate the world to our advantage. The problem, in other words, is not simply that burning oil releases carbon dioxide, which happens, by virtue of its molecular structure, to trap the sun's heat. The problem is that nature, the independent force that has surrounded us since our earliest days, cannot coexist with our numbers and our habits. We may well be able to create a world that can support our numbers and our habits, but it will be an artificial world—a space station.

Or, just possibly, we could change our habits.

ONE very small example of an idea so large as to be unwieldy: To cope with the greenhouse world, people in the developed countries will probably begin to install much more energy-efficient washing machines. That would reduce somewhat the amount of carbon dioxide each of us puffs into the atmosphere. But what if, instead, people got together with their neighbors and agreed to buy a single washing machine for the entire block (not such a novel concept to people in big-city apartment houses)? And what if they also decided that instead of continually buying fashionable clothes they would reduce their wardrobes to a comfortable, or even uncomfortable, minimum? What if, in other words, we began to reject a pervasive individual consumerism, and began to alter a basic way we look at ourselves? Mightn't such a path, broadened to include other facets of daily life, offer the best way not only to avoid overheating the planet but also to keep from transforming it in the other sad ways I have discussed?

As long as the desire for endless material advancement drives us, there is no way to set limits. We are unlikely to develop genetic engineering to eradicate disease and then not use it to manufacture perfectly efficient chickens; there is nothing in the logic of our beliefs that would lead us to draw that line. If there is one item that virtually all successful politicians on earth—socialist and fascist and capitalist—agree on, it is that "economic growth" is good, necessary, the proper end of organized human activity.

Our present environmental troubles, though, just might give us the chance to change the way we think. Spurred by the realization of what we have done, we might begin to think and then

behave more humbly. As the effects of man's domination have become clearer in recent years, a new idea has begun to spread, both in America and abroad. Some environmentalists have begun to talk of two approaches to the world: the traditional anthropocentric view, and the biocentric vision of mankind as just another part of the world. This concept is foreign to most of us. My first sense of what it might mean came a couple of summers ago in Idaho, when I was camped next to a man who hikes almost every year from Mexico to Canada. A dozen times, he told me, he had met grizzly bears, the grandest mammals left on the continent: "The last one, he stood on his hind legs, clicked his jaws, woofed three times. I was too close to him, and he was just letting me know. Another one, he circled me about forty feet away and wouldn't look me in the eye. When you get that close, you realize you're part of the food chain."

The idea that man doesn't necessarily belong at the top—that the hierarchy we've spent many thousands of years establishing is dangerous to other species and also to ourselves—is a strange and powerful idea. The few philosophers and environmentalists interested in such a Copernican shift have taken to calling this alternative path "deep ecology"—as opposed to the "shallow ecology" of conventional environmentalism, which seeks merely to turn mankind into better stewards. Deep ecology suggests that instead of just giving better orders we learn to give fewer and fewer orders—to sink back into the natural world. Deep ecologists question the industrial basis of our civilization, the need to forever grow in wealth and numbers, the entire way we live. We should, they say, work toward a smaller world population—half the current one, maybe, or even less. And we should lay aside our desire for material advancement in favor of "doing with enough."

Such ideas are not blueprints; they aren't even outlines. But they are at least a starting point for those who seek to save a world fast vanishing. They are radical ideas, but we live at a radical moment. We live at the end of nature, the instant when the essential character of the world is changing. If our way of life is ending nature, it is not radical to talk about transforming our way of life. When I climb the hill out back, I often pause on a ledge from

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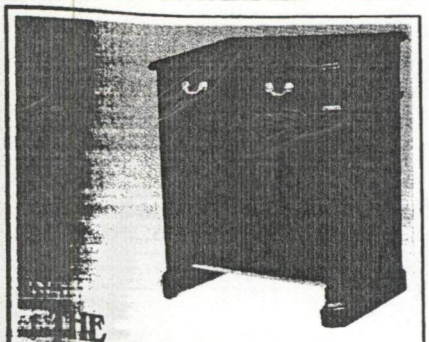

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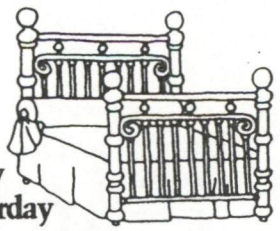

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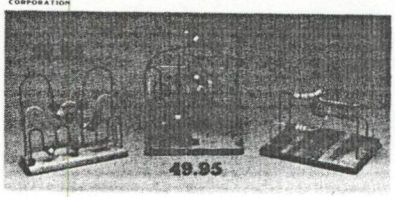

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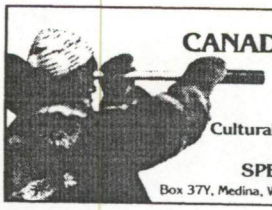

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which I can see my house—the car in the driveway, the chimney above the stove. I love the life that that house represents, love it very much. But I love the hemlocks around me on the hill, too, and the coyotes, and the deer. And it seems that either that life down there must change or the life up here around me will change—the trees will wilt in the sun or else sprout in perfect, heat-tolerant, genetically improved rows.

Exactly what a humbler world would look like I cannot say. We are used to planning utopias, worlds engineered for human happiness. But this would be something different—an "atopia," perhaps, where the integrity of the planet, and not our desires, would be the engine. If our thinking changed, the details would follow of their own accord. Perhaps we might all begin to use the "appropriate technology" of "sustainable development" which we urge on Third World peasants—solar cookstoves, or bicycle-powered pumps. Probably many more of us would be growing our own food. Such solutions are not beyond our imagination. When we decided that accumulation and growth were our economic ideals, we invented wills and lending at interest and puritanism and supersonic aircraft. Why would we come up with ideas less powerful in an all-out race to do with less?

The difficulty in accomplishing this transformation is almost certainly more psychological than intellectual—less that we can't figure out major alterations in our way of life than that we don't want to. The people whose lives may point the way—Thoreau, say, or Gandhi—we dismiss as exceptional, a polite way of saying that there is no reason we should be expected to go where they pointed. The challenge they presented with the example of their lives is much more subversive than anything they wrote or said, for if they could live that simply it's no use saying we couldn't. And maybe now we should—not just for moral or aesthetic reasons but for reasons of chemistry and physics.

Such a change would obviously be colossally difficult. For one thing, while we as individuals would have to change our habits, it would mean very little—save as a good gesture—for any one of us to, say, drive less. *Most* people have to be persuaded to drive less, and persuaded quickly; this is the first environmental crisis one can't escape by heading for the woods. It's also difficult for us to turn our backs on the idea of economic growth, because it has been sold as the answer to the poverty that afflicts most of the planet. For example, S. Fred Singer, the greenhouse skeptic, writes, "Drastically limiting the emission of carbon dioxide means cutting deeply into global energy use. But limiting economic growth condemns the poor, especially in the Third World, to continued poverty, if not outright starvation." I am sometimes dubious about the actual depth of feeling for the Third World such arguments imply; they mesh too conveniently with our desires. An overheated, ozone-depleted world would probably be crueller to the poor than to the rich, and if our desire is to alleviate poverty, limiting our standard of living and sharing our surplus would likely work as well. But I have no doubt about the power of arguments like Singer's to stall effective action of any sort if we are reluctant to take such action in the first place.

STILL, problems like the inertia of affluence, the push of poverty, and the soaring population are traditional problems. We can think about them, deal with them, perhaps overcome them. In my lifetime, in this country, we have gone from Jim Crow to affirmative action, and there is no saying we can't do something similar with regard to the planet.

I fear that we won't, though, and for an entirely different set of reasons—reasons intimately linked to the unique and depressing moment in which we find ourselves. As we have seen, nature is already ending. And not only does its passing prevent us from returning to the world we previously knew but also, for a couple of powerful reasons, it makes any of the fundamental changes I've discussed even more unlikely than they might be in easier times.

In the first place, the end of nature is a plunge into the unknown, fearful as much *because* it is unknown as because the world may become hot or dry or whipped by hurricanes. But the type of shift in attitudes I've been describing—the deep-ecology alternative, for instance—would make life even more unpredictable. One would have to begin to forgo the traditional methods of securing one's future—children, possessions, and so on. As the familiar

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world around us starts to change, every threatened instinct will have us scrambling to preserve at least our familiar style of life. We can—we may well—make the adjustments necessary for our survival. For instance, some of the early work in agricultural biotechnology has focussed on inventing plants able to survive heat and drought. It seems the sensible thing to do—the way to keep life as "normal" as possible in the face of change. It leads, though, as I have said, to the second end of nature: the imposition of our artificial world in place of the broken natural one.

I got a glimpse of this particular future a few years ago, when I spent some time along the La Grande River in sub-Arctic Quebec. It is barren land but beautiful—a taiga of tiny ponds and hummocks stretching to the horizon, carpeted in light-green caribou moss. There are trees—almost all black spruce, and all spindly, sparse. No one lived there save a small number of Indians and Eskimos—about the number the area could support. A decade or so ago, Hydro-Québec, the provincial utility, decided to exploit the power of the La Grande by building three huge dams along a three-hundred-and-fifty-mile stretch of the river. The largest is the size of fifty-four thousand two-story houses, a Hydro-Québec spokesman told me. Its spillway could carry the combined flow of all the rivers of Europe. Erecting it was a Bunyanesque task: eighteen thousand men carved the roads north through the taiga and poured the concrete. (Photographs show the cooks stirring spaghetti sauce with canoe paddles.) This is the perfect example of "environmentally sound" energy generation; the dams produce a tremendous amount of power without giving off any greenhouse gas. They are the sort of structure we will be clamoring to build as the warming progresses.

But environmentally sound is not the same as natural. The dams have altered an area larger than Switzerland. The flow of the Caniapiscau River has been partly reversed to provide more water for the turbines. In September of 1984, at least ten thousand caribou drowned trying to cross the river during their annual migration. They were crossing at their usual spot, but the river was not its usual size; it was so swollen that many of the animals were swept forty-five miles downstream. Every good

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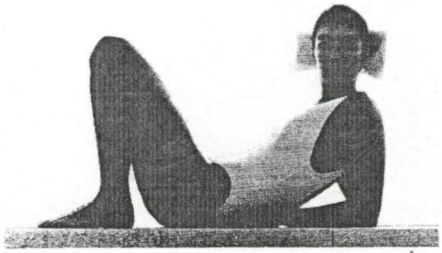

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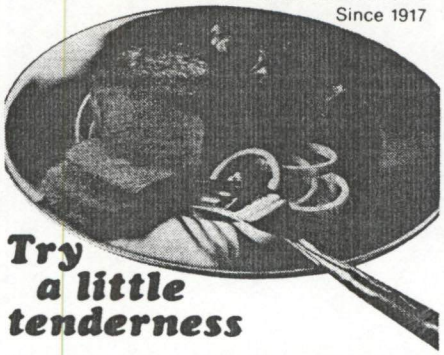

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argument—the argument that fossil fuels cause the greenhouse effect, the argument that in a drier, hotter world we will need more water, the argument that as our margin of security dwindles we must act to restore it—will lead us to more La Grande projects, more dams on the Colorado, more "management." Every argument that the warmer weather and increased ultraviolet are killing plants and causing cancer will have us looking to genetic engineering for salvation. And with each such step we will move farther from nature.

And as that happens the counter-argument—the argument for nature—will grow ever fainter. Wendell Berry once argued that in the absence of a "fascination" with the wonder of the natural world "the energy needed for its preservation will never be developed"—that "there must be a mystique of the rain if we are ever to restore the purity of the rainfall." This makes sense when the problem is transitory—sulfur-dioxide emissions drifting over the Adirondacks. But how can there be a mystique of the rain, now that every drop—even the drops that fall as snow on the Arctic, even the drops that fall deep in the remaining forest primeval—bears the permanent stamp of man? Having lost its separateness, nature loses its special power. Instead of being a category like God—something beyond our control—it is now a category like the defense budget or the minimum wage, a problem we must work out. This alone changes its meaning completely, and changes our reaction to it. The end of nature probably also makes us reluctant to attach ourselves to its remnants, for the same reason that we usually don't choose new friends from among the terminally ill. I love the mountain outside my back door—the stream that runs along its flank, and the stream that slides down a quarter-mile mossy chute, and the place where the slope flattens into an open plain of birch and oak. But I know that in some way I resist getting to know it better—for fear, weak-kneed as it sounds, of getting hurt. I fear that if I knew as well as a forester what sick trees look like I would see them everywhere. I find now that I like the woods best in winter, when it is harder to tell what might be dying, but I try not to love even winter too much, because of the January perhaps not so distant when the snow will fall as warm rain. There is no future in loving nature.

And there may not even be much past. Though Thoreau's writings grew in value and importance the closer we drew to the end of nature, the time fast approaches when he will be inexplicable, his notions less comprehensible to future men than cave paintings are to us. Thoreau writes of the land around Katahdin that it "was vast, Titanic, and such as man never inhabits. Some part of the beholder, even some vital part, seems to escape through the loose grating of his ribs. . . . Nature has got him at a disadvantage, caught him alone, and pilfers him of some of his divine faculty. She does not smile on him as in the plains. She seems to say sternly, Why came ye here before your time. This ground is not prepared for you." That sentiment describes perfectly the last stage of the relationship of man to nature; though we had subdued her in the low places, the peaks, the poles, the jungles still rang with her pure message. But what will this passage mean in the years to come, when Katahdin, the "cloud factory," is ringed by clouds that are the work of man? When the great pines around its base have been genetically improved for straightness of trunk and "proper branch drop," or, more likely, have sprung from the cones of genetically improved trees that began a few miles and a few generations distant on some timber plantation? When the moose that ambles by is part of a herd whose rancher is committed to the enlightened notion that "conservation and profit can go hand-in-hand"? Soon Thoreau will make no sense. And when that happens the end of nature, which began with our alteration of the atmosphere and continued with the responses of the planetary managers and the genetic engineers, will be final. The loss of memory will be the eternal loss of meaning.

I understand perfectly well that defiance may bring prosperity, and a sort of security—that more hydropower will mean less carbon dioxide, and that genetic engineering will help the sick,

and that much progress can still be made against human misery. And I have no plans to live in a cave, or even in an unheated cabin. If it took twelve thousand years to get where we are, it will take a few generations to climb back down. But this could be the epoch in which people decide at least to go no farther along the path we have been following—when we make not only the necessary technological adjustments to preserve the world from overheating but also the necessary mental adjustments to insure that we will never again put our good ahead of everything else's. This is the path I choose, for it offers at least a shred of hope for a living, eternal, meaningful world.

As birds have flight, our special gift is reason. Part of that reason drives the intelligence that allows us to master DNA or build big power plants. But our reason could also keep us from following blindly the biological imperatives toward endless growth in numbers and territory. Our reason allows us to conceive of our species as a species, and to recognize the danger that our growth poses to it, and to feel something for the other species we threaten. Should we so choose, we could exercise our reason to do what no other animal can do: we could limit ourselves voluntarily, choose to remain God's creatures instead of making ourselves gods. What a towering achievement that would be, so much more impressive than the largest dam—beavers can build dams—because so much harder. Such restraint, not genetic engineering or planetary management, is the real challenge. If we now, today, began to limit our numbers and our desires and our ambitions, perhaps nature could someday resume its independent working. Perhaps the temperature could someday adjust itself down to its own setting, and the rain fall of its own accord. —BILL MCKIBBEN

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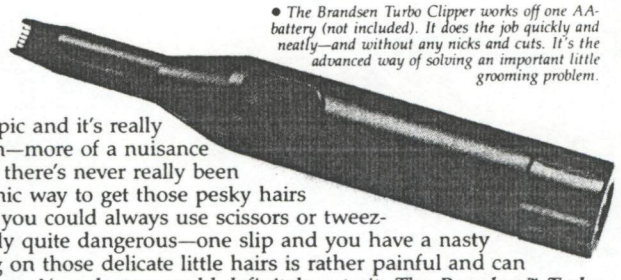

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Tues

8-24 accepted

8-21-89 Requested for DAB - explained that Dr Ratchford would brief DAB on his meeting with the MPs. MCE

9/19

Jr Tatlem 898-4324

"DOCUMENT TRACKING"

DOCUMENT NO: 27

TYPE: Meeting Request **DATE OF DOCUMENT:** 8/2/89

LOCATION: Science Office
TIME: 3:30 - 4:30 pm

CONTACT PERSON: Dr. D. J. Yarrow
CONTACT NO: (202) 462-1340
British Embassy

INVITATION ACCEPTED: **YES** **NO**

FROM: House of Lords Science & Technology Committee and House of Commons Energy Committee

TO: Bromley

SUBJECT: Greenhouse effect policy and action by United Kingdom required.

ASSIGNED TO: Post/MCE

ACTION REQUIRED: Talking points and acknowledgement

3

SENDER'S DUE DATE: XX

OSTP DUE DATE: 8/29/89 TP

DATE COMPLETED: 8/23/89

8:45 - 9:45 September 19 2 persons

COPIES TO: Ratchford/Bowden
Earth Sciences
Rona

FILE: NEOB **DATE RECEIVED:** 8/9/89

REMARKS:
Received the report issued by the Energy Committee on "Energy Policy Implications of the Greenhouse Effect".

They will be in town from Sept. 17th - 21st.

Dr. Bromley will be out of town from Sept. 19 thru 21.

8-11-89

8-21-89 regrets

Mary Catherine comments ??

8-11-89

Since Dr. Bromley will be away, probably Tom Rona and Tom Ratchford should meet these members of Parliament.

MCE

8-21-89 not yet scheduled for Dept with Ratchford at AAAS

Did they? DAB

British Embassy
3100 Massachusetts Avenue NW Washington DC 20008
Telex Domestic USA 89-2370/89-2384
Telex International 64224(WUI)/440015(ITT)
Telephone (202) 462-1340

Your reference

Our reference

Date

2 August 1989

Dr Alan Bromley
Director-Designate
Office of Science and Technology Policy
Room 358,
Old Executive Office Building
Washington DC 20506

Dear Dr Bromley

VISIT TO WASHINGTON BY HOUSE OF LORDS SCIENCE AND TECHNOLOGY COMMITTEE AND HOUSE OF COMMONS ENERGY COMMITTEE

1. The above Committees are visiting Washington from 17-21 September in connection with their current enquiries related to the greenhouse effect. The Chairman of the Lords' Science Committee, Lord Carver, has asked if it would be possible to meet with you to discuss climate change research.

2. The Lords' Committee is carrying out an enquiry with the following terms of reference:

> "to consider the scientific grounds on which policy relating to the greenhouse effect should be based, and what action by the United Kingdom is required."

I attach a note which sets out some of the questions the Committee has been addressing whilst holding hearings in the UK and which illustrates some of the issues the Committee wishes to discuss whilst in the US. The Lords Committee will report in due course to the UK Government.

3. The House of Commons Energy Committee has been looking into the energy policy implications of the greenhouse effect and last month reported to Government. It is now considering the need for an international convention to combat global warming.

4. If you are able to meet members of the Committees we would of course do all we can to fit into your schedule. A meeting from 3.30-4.30pm on Wednesday September 20 would be particularly convenient however.

5. I attach details of the UK visiting party together with short biographies.

Yours sincerely,

Dr D J Yarrow
First Secretary (Science)

RECEIVED

89 AUG 9 A11 : 57

OFFICE OF THE
DIRECTOR

BRITISH EMBASSY
3100 Massachusetts Avenue NW Washington DC 20008

Telex: Domestic USA 89-2370/89-2384
Telex: International 64224(WUI)/440015(ITT)
Telephone: (202) 462-1340

Dr Alan Bromley
Director-Designate
Office of Science & Technology Policy
Room 358 Old Executive Office Building
Washington DC 20506

Your reference

Our reference

Date 24 August 198

Dear Dr Bromley

HOUSE OF LORDS SELECT COMMITTEE ON SCIENCE AND TECHNOLOGY
AND HOUE OF COMMONS ENERGY COMMITTEE

I am writing to confirm that the above Committee will be visiting you on Tuesday 19th September from 8.45-9.45am.

I enclose a list of the Committee members who will be attending the meeting plus their biographies. Would you please also note that the Committee will be accompanied by Mr Alastair Allcock, Counsellor, Science Technology and Energy and Dr Doug Yarrow, First Secretary (Science).

Yours sincerely,

Liz Tattum

Liz Tattum
Secretary to Dr D J Yarrow
First Secretary (Science)

VISIT OF UK SELECT COMMITTEES

House of Lords Committee on Science and Technology

Lord Carver	
Lord Dainton	
Lord Flowers	
Lord Sherfield	
Andrew Gilchrist	(Specialist Adviser - until recently Director of Research at Meteorological Office)
Rhodri Walters	(Clerk)

House of Commons Select Committee on Energy

Sir Ian Lloyd	MP	(Chairman)
Mr Ted Leadbitter	MP	
Mr Eric Illsley	MP	
Chris Stanton		(Clerk)

Accompanied by a representative of the British Embassy

ISSUES TO BE ADDRESSED BY THE HOUSE OF LORDS SELECT COMMITTEE ON SCIENCE AND TECHNOLOGY

The House of Lords Select Committee on Science and Technology has set up a Sub-Committee, under the Chairmanship of Lord Carver, to consider the scientific grounds on which policy relating to the greenhouse effect should be based, and what action by the United Kingdom is required.

In holding hearings in the UK, the Committee has asked those giving evidence to consider the following questions:

a. what is your assessment of the scientific evidence of global warming from the greenhouse effect?

b. in the light of that, what consequences do you foresee from present or predicted global warming; how probable are these consequences, and over what timescale?

c. what are the areas in which greater effort, national and international, is required in order either to improve our knowledge of the greenhouse effect, or to improve our understanding of its likely consequences?

d. what additional research resources or facilities are therefore required?

e. arising out of your conclusions on the above questions, what policy and further action, either national or international, would you advocate?

DAINTON (Life Baron, UK), Frederick Sydney Dainton; cr. 1986. Kt 1971; ScD; LLD; DTech; FRS 1957.

Son of the late George Whalley Dainton, stonemason. B. November 11, 1914; ed. Central Secondary School, Sheffield, St John's College, Oxford and Sidney Sussex College, Cambridge; m. August 27, 1942, Barbara Hazlitt, d. of Dr W. B. Wright (1s 2d). Fellow and Lecturer, St Catharine's College, Cambridge 1944-50. Professor of Physical Chemistry, Leeds University 1950-65. Vice-Chancellor, Nottingham University 1965-70. Professor of Chemistry, Oxford University 1970-73. Chrmn, University Grants Committee 1973-78. Chrmn, British Library Board and National Radiological Protection Board 1978-85. Chancellor, Sheffield University 1979-. Chrmn, Edward Boyle Memorial Trust 1982. Pres. Faraday Society 1965-67. Pres. Chemical Society 1972-73. Trustee, British Museum (Natural History) 1974-84. Trustee, Wolfson Foundation 1979-88. Member, Court of Assistants, Goldsmiths' Company 1973-; Prime Warden 1982-83. Holder of the Tilden and Faraday Medals, Chemical Soc; Davy Medal, Royal Society 1969; Curie Medal (Poland) 1983 and 34 Hon Doctorates and Fellowships. A Cross-Bencher. *Special Interests*: Higher education, information and libraries, Science and technology policy. *Recreation*: Gardening. Raised to the peerage as Baron Dainton, of Hallam Moors in the County of South Yorkshire 1986. *Address*, *The Lord Dainton, Fieldside, Water Eaton Lane, Oxford OX5 2PR* (08675-5132) *Club*: *Athenaeum*

SHERFIELD (1st Baron, UK), Roger Mellor Makins; cr. 1964; GCB 1960; GCMG 1955; DL.

Son of Brigadier-General Sir Ernest Makins, KBE, CB, DSO. B. Feb. 3, 1904; ed. at Winchester and Christ Church Oxford; m. April 30, 1934, Alice (d. 1985), e.d. of the late Hon. Dwight F. Davis (2s 4d). Fellow of All Souls Coll. Barr-at-Law 1927; Foreign Office 1928. Deputy Under-Secretary of State for Foreign Affairs 1948-52. HM Ambassador to Washington 1953-56. Joint Permanent Secretary, Treasury 1956-60; Chrmn United Kingdom Atomic Energy Authority 1960-64; Industrial and Commercial Finance Corporation 1964-74. Wells-Fargo Ltd 1972-84; A. C. Cossor Ltd 1966-84; Finance for Industry Ltd 1973-74; Hill Samuel Group Ltd 1966-70; Governing Body Imperial College of Science & Technology 1962-74. Pres. Parl. and Scientific Cttee 1969-72, Chancellor, Univ. of Reading, Warden of Winchester Coll. 1974-79. Select Cttee on Science and Technology 1980-, Chrmn 1984-87. Pres. Centre for International Brieting Farnham Castle 1972-84. Hon. DCL (Oxon). Hon. LLD (London). Hon. Student Christ Church, Oxford. DL (Hants) FICE. Hon. DLitt Reading. FRS 1986. A Cross-Bencher. *Recreations*: Gardening, shooting. Heir, his son, Hon. Christopher James Makins, b. July 23, 1942. *Address*, *The Lord Sherfield, 81 Onslow Square, SW7; Ham Farm House, Ramsdell, Nr Basingstoke, Hampshire, RG26 5SD* (07356 3526). *Clubs*: *Boodle's, Pratt's, MCC*.

FLOWERS (Life Baron, UK), Brian Hilton Flowers; cr. 1979; Kt. 1969; FRS 1961.

Son of the late Rev. Harold Joseph Flowers. B. Sept. 13, 1924; ed. Swansea Grammar Sch.; Gonville & Caius Coll., Cambridge (MA) & University of Birmingham (DSc); m. Oct. 26, 1951 to Mary Frances, elder d. of the late Sir Leonard F. Behrens, CBE; (2 step-s). Anglo-Canadian Atomic Energy Project (Tube Alloys) 1944-46. Atomic Energy Research Establishment, Harwell 1946-58. Prof. of Theoretical Physics, Univ. of Manchester 1958-61. Langworthy Prof. of Physics, Univ. of Manchester 1961-72. Chrmn of Computer Board for Univs. & Research Council 1966-70. Chrmn of Science Research Council 1967-73. Member. of Atomic Energy Authority 1971-81; Pres. of Inst. of Physics 1972-74. Chrmn. of Royal Comm. on Environmental Pollution 1973-76. Rector of Imperial Coll. Univ. of London 1973-85. Pres. of European Science Foundation 1974-80; Chrmn of Commn on Energy and the Environment 1978-81. Managing Trustee of the Nuffield Foundation 1982- and chairman of the Nuffield Foundation 1987-. Chrmn of the Committee of Vice-Chancellors and Principals for 1983-85. Vice-Chancellor of London University 1985-. A Social Democrat. *Special Interests*: Higher Education, Science and Technology. *Recreations*: Music, walking, gardening, computing. Raised to the peerage as Baron Flowers, of Queen's Gate in the City of Westminster 1979. *Address*, *The Lord Flowers, Kt. FRS, University of London, Senate House, Malet St, London WC1E 7HU* (01-636 8000).

CARVER (Life Baron, UK), Richard Michael Power Carver; cr. 1977. GCB 1970; CBE 1945; DSO 1943 and Bar 1943, MC 1941.

Son of late Harold Power Carver (d. 1948). B. April 24, 1915; ed. Winchester and RMC Sandhurst; m. Nov. 22, 1947 Edith, d. of late Sir Henry Lowry-Corry (2s 2d). Comd. 4th Armd Bde 1944-47. Dep. Ch. of Staff, E. Africa 1954-55; Ch. of Staff, E. Africa 1955-56. Dir. Army Plans 1958-59. Comd 6th Bde 1960-62. GOC 3rd Divn 1962-64. Dir. Army Staff Duties 1964-66. Comd Far East Land Forces 1966-67. C-in-C Far East 1967-69. GOC in C Southern Command 1969-71. Ch. of General Staff 1971-73. Ch. Defence Staff 1973-76. Field Marshal 1973. Author of *El Alamein* (1962), *Tobruk* (1964), *Harding of Petherton* (1978), *The Apostles of Mobility* (1979), *War Since 1945* (1980) and *A Policy for Peace* (1982), *The Seven Ages of the British Army* (1984), *Dilemmas of the Desert War* (1986), *Twentieth Century Warriors* (1987). Editor *The War Lords* 1976. A Cross-Bencher. *Special Interest*: Defence. *Recreations*: Gardening, sailing, tennis. Raised to the peerage as Baron Carver, of Shackleford in the County of Surrey 1977. *Address*, *Field Marshal Lord Carver, GCB, CBE, DSO, MC, Wood End House, Wickham, Nr. Fareham, Hants. PO17 6JZ* (0329 832143) *Clubs*: *Anglo-Belgian, Cavalry and Guards*.

HOUSE OF COMMONS ENERGY COMMITTEE

LLOYD, Sir Ian Stewart. (*Havant*) *C. majority 16,510*

S. of late W. J. Lloyd. B. May 30, 1921; ed. at Michaelhouse (Natal), Witwatersrand Univ. and King's Coll. Cambridge (MA, MSc.); m. Frances Dorward, d. of The Hon. W. Addison, CMG, OBE, DCM, MC (3s). Formerly Economic Adviser to the British and Commonwealth Shipping Group. Formerly an adviser to the Minister of Transport on Maritime Research Policy. Pilot SAAF 1941–45. Training Command and No. 7 (Spitfire) Squadron. Economic Adviser to the Central Mining and Investment Corpn 1949–53. Led the UK delegations to the 5th and 6th biennial International Conferences of the International Cargo Handling Co-ordination Assn Sept. 1961, Oct. 1963. British Delegation, Council of Europe and Western European Union 1968–72. Member Select Cttee on Science and Technology 1971–79. Chrmn Select Sub-Cttee on Science 1975. Chrmn Select Sub-Cttee on Technological Innovation 1976–79. Chrmn Select Cttee on Energy 1979–. Chrmn All-Party Cttee on Information Technology 1979–87. Vice-President, Parliamentary and Scientific Cttee 1984–87, Vice Chrmn 1988–. Chrmn Advisory Board, Parliamentary Office of Science and Technology 1988–. Kt 1986. Author of *Rolls-Royce: The Growth of a Firm; Rolls-Royce: The Years of Endeavour; Rolls-Royce: The Merlin at War*, Macmillan 1978. *Special Interests:* Energy Policy, Information Technology, Science Policy in UK, Southern Africa, Japan, Micro-electronics in schools. *Recreations:* Music, sailing, cutting grass. Member for Portsmouth, Langstone div. 1964–74, for Havant and Waterloo 1974–83 and for Havant since June 1983.—*Bakers House, Prior Dean, Nr Petersfield, Hants.; House of Commons* (01-219 4004); *Clubs: Brooks's, Royal Yacht Squadron.*

LEADBITTER, Ted. (*Hartlepool*) *Lab. majority 7,289*

S. of Edward Leadbitter. B. June 18, 1919; ed. at state schools teachers' training college; m. Phyllis Irene Mellin (1s 1d). Teacher. Joined the Labour Party 1938. Formerly member of NUGMW and now member of NUPE. Commissioned Royal Artillery 1941. War Office Commissioned Instructor in Gunnery. Organiser of the Exhibition on the History of Labour Movement 1941–56. Member of West Hartlepool Borough Council 1954–67. Chrmn of various Local Government Cttees Pres. Hartlepool Constituency Labour Party 1956–58. Member of Estimates Cttee, House of Commons 1966–69. Member of Select Cttee House of Commons on Science and Technology 1969–78. Chrmn Parl. Anglo-Tunisian Group 1972–. Chrmn PLP Ports Cttee 1974–. Member Select Cttee on Energy. Chairman's Panel, House of Commons. Education officer, Hartlepool, and leader of Labour Group 1961 and 1962. Honorary Freeman of Borough of Hartlepool Feb. 1981. Freeman of London July 1986. Sponsored Registration of Children's Homes Act 1981. *Special Interests:* Energy, Transport, Ports, Regional Development. *Recreations:* Painting, writing, chess, walking. Member for Hartlepool since Oct. 15, 1964.—*30 Hylton Road, Hartlepool, Co. Durham* (0429 263404); *Constituency Office* (0429 272423); *House of Commons* (01-219 3000).

ILLSLEY, Eric. (*Barnsley Central*) *Lab. majority 19,051*

S. of John and Maud Illsley. B. April 9, 1955; ed. Barnsley Holgate Grammar School and Leeds University; m. Sept 16, 1978, Dawn, d. of Robert and Freda Webb (2d). Yorkshire Area NUM compensation officer 1978–81. Asst Head of General Dept 1981–84. Head of General Dept and Chief Admin. Officer 1984—87. Member House of Commons Select Cttee on Energy and on Televising Proceedings of the House of Commons. *Special Interests:* Trades Unions, Mining, Energy, Social Security. *Recreations:* Squash. Member for Barnsley Central since June 1987.—*House of Commons, SW1A 0AA* (01-219 3501); *Constituency Office* 0226 730692).

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