NORTHWEST POWER PLANNING COUNCIL

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March 12, 1990

Dear Interested Party:

Attached is a copy of the proceedings of the symposium "Global Warming: A Northwest Perspective" held in February 1989. This symposium was sponsored by the Northwest Power Planning Council and co-sponsored by the Oregon Department of Energy, Pacific Northwest Laboratory and Washington State Energy Office.

The Council found this was a very useful and interesting conference in its efforts to incorporate environmental considerations into electric energy planning. Topics ranged from the causes, effects and timing of global warming to the design of policy in response to global warming potential.

The Council is continuing its work to incorporate environmental considerations in its energy planning as its develops its 1990 Power Plan.

Sincerely,

Edward Sheets

Edward Sheets
Executive Director

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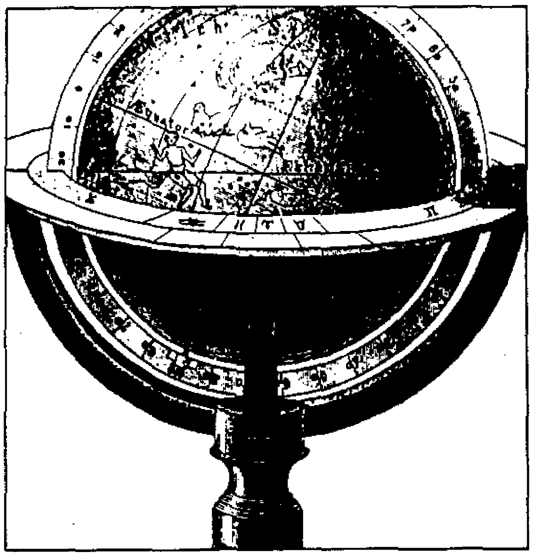
Proceedings

Global Warming: A Northwest Perspective

Symposium held
February 9, 1989
Olympia, Washington



February 1990

Prepared by
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Proceedings

GLOBAL WARMING: A NORTHWEST PERSPECTIVE

Symposium held
February 9, 1989
Olympia, Washington

Editors:
M. J. Scott
C. A. Counts

February 1990

Sponsor:
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Prepared by
Pacific Northwest Laboratory
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Pacific Northwest Laboratory
Richland, Washington 99352

PREFACE

On February 9, 1989, the Northwest Power Planning Council convened a symposium in Olympia, Washington, on the subject of global climate change ("the greenhouse effect") and its potential for affecting the Pacific Northwest. Cosponsoring the symposium were the Pacific Northwest Laboratory,[a] the Washington State Energy Office, and the Oregon Department of Energy. The symposium was organized in response to a need by the Power Council to understand global climate change and its potential impacts on resource planning and fish and wildlife planning for the region, as well as a need to understand national policy developing toward climate change and the Pacific Northwest's role in it.

The symposium gathered several nationally and internationally recognized scientists and policy analysts who explored the causes, effects, likelihood, and timing of global warming; its potential impact on the Pacific Northwest; and related national and regional policy. The morning session, *Global Warming: Causes and Effects*, focused on the causes and consequences of global warming, and conveyed the state of the science concerning the topic. The afternoon session, *Global Warming: Toward a Regional Response*, focused on policy aspects of controlling greenhouse gas emissions at both the national and regional levels and discussed actions to deal with the uncertainty of the global warming phenomenon and its potential effects.

(a)Pacific Northwest Labortory is operated for the U.S. Department of Energy by Battelle Memorial Institute. The workshop was partially funded under contract DE-AC06-76RLO 1830.

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1.0 GLOBAL WARMING AND THE PACIFIC NORTHWEST: EDITOR'S INTRODUCTION

Michael J. Scott, Pacific Northwest Laboratory
Richland, Washington

On February 9, 1989, the Northwest Power Planning Council convened a symposium in Olympia, Washington, on the subject of global climate change ("the greenhouse effect") and its potential for affecting the Pacific Northwest. The Power Council was joined in sponsoring the symposium by the Pacific Northwest Laboratory (PNL), operated by Battelle Memorial Institute for the U.S. Department of Energy (DOE); by the Washington State Energy Office; and by the Oregon Department of Energy. The introductory speaker for the symposium was Mr. Tom Trulove, Chairman of the Power Council. In his introductory remarks, Mr. Trulove noted that the symposium was organized in response to a need by the members of the Power Council to understand global climate change and its potential impacts on resource planning and fish and wildlife planning for the region, as well as a need to understand national policy developing toward climate change and the Pacific Northwest's role in it. The symposium explored the causes, effects, likelihood, and timing of global warming, and its potential impact on the Pacific Northwest and related national and regional policy.

The morning session, *Global Warming: Causes and Effects*, focused on the causes and consequences of global warming. Dr. John Harte, an environmental scientist with the Energy Resources Group at the University of California, Berkeley, led off the day's discussions with an overview of the greenhouse effect, its causes, and the expected worldwide effects. In his overview role, Dr. Harte stated at the outset that he would distinguish among "the things we feel quite certain about, the things we are pretty sure about but for which there is still good honest debate and the need for more research, and the things we are almost entirely in the dark about." He was followed by Dr. Michael Schlesinger, climate modeler from Oregon State University,[a] and, in his own words, "one of about ten people in the world" building general circulation models (GCMs) to describe the world's atmosphere and climate and the response of the world's climate to elevated concentrations of carbon dioxide and other trace gases. Dr. Schlesinger discussed at length the methods that are used for forecasting climate change and the magnitude, timing, geographic distribution, and uncertainties of climate change as predicted by GCMs.

Two speakers concluded the morning session with talks on the consequences of climate change for the Pacific Northwest. Dr. Dennis Lettenmaier of the University of Washington described the findings of his U.S. Environmental Protection Agency (EPA) sponsored study in California and the meaning of a shift from snow-dominated to rain-dominated hydrology for the Pacific Northwest. Dr. Duane Neitzel of PNL discussed the potential impact of global warming on Pacific Northwest salmon and steelhead stocks, based on findings of differences in salmonid abundance in the archeological record for the warmer Hypsithermal period (6,000 years ago) and the findings of a number of fisheries scientists on the consequences of warmer climate.

The luncheon speaker was Governor Booth Gardner of the State of Washington. He made several well-received remarks on the greenhouse effect as an example of another environmental problem caused by our energy choices and on the importance of increased energy efficiency as a cost-effective tool for controlling greenhouse gas emissions. Governor Gardner's remarks set the stage for the afternoon session.

The afternoon session, titled *Global Warming: Toward a Regional Response*, focused on several aspects of controlling greenhouse gas emissions at both the national and regional levels. Dr. Gordon J. MacDonald of the Mitre Corporation led off the discussion with a talk on sources of greenhouse gases at the international level, emphasizing the role of the United States, impact of the electric utility

(a) Dr. Schlesinger is now affiliated with the University of Illinois - Urbana.

industry, and the comparative emissions of coal-fired and gas-fired technologies. A major theme of Dr. MacDonald's talk was a fallacy he detected in federal policy: encouraging production and use of synfuels based on coal without a direct assessment of the associated environmental consequences. He was followed by Mr. Dick Watson of the Washington State Energy Office, who emphasized the role of transportation as a major factor in Pacific Northwest emissions of carbon dioxide, and also emphasized the importance of energy conservation as a tool of control that makes economic sense beyond its salutary effects on greenhouse gas emissions. Dr. Peter Beedlow of the EPA Corvallis Laboratory explained the current course of EPA research on regional impacts of global warming. Regional impacts are currently some of the least understood aspects of the global warming phenomenon.

The last two speakers of the day were Mr. Ralph Cavanagh of the Natural Resources Defense Council and Mr. Michael Totten, member of the staff of U.S. Representative Claudine Schneider (R-Rhode Island). Mr. Cavanagh spoke on the role of energy efficiency at the regional level. He emphasized the implementation of the Power Council's Model Conservation Standards for residential housing as part of the building code and the adoption of revised commercial building standards as two major pieces of unfinished business. In his presentation, Mr. Totten also discussed energy efficiency as a major source of emissions control, and brought to the Power Council's attention several technical advances in the energy efficiency of transportation, commercial and domestic lighting, and high-efficiency combustion turbines for power generation. The day concluded with questions and answers of the afternoon panel.

There was a major message that emerged from the symposium that was reiterated by most of the speakers on the program: the timing and effects of global warming are highly uncertain, but the best near-term solution to the problem is to do what makes sense anyway. Global warming resulting from human activities is at least partly a byproduct of the same inefficient use of fossil energy that has given rise to other, more familiar problems such as local air pollution, high energy bills, etc. Even though the Pacific Northwest is a small contributor to the worldwide atmospheric buildup of carbon dioxide and other greenhouse gases, more efficient use of energy in the region makes sense for other reasons closer to home: reducing urban traffic congestion, lowering heating bills, reducing the capital costs of new electrical generating capacity. The greenhouse problem is yet one more reason for concern over energy inefficiency.

There was also a message from the symposium for utilities and planning groups such as the Power Council. That message was to stay flexible and take the uncertainty concerning greenhouse effects into account. One may reasonably argue with the proposition that the Pacific Northwest has a "mission" to demonstrate that energy efficiency is the way to deal with the greenhouse effect, as some of the speakers implied. One may also reasonably argue with the proposition that the Pacific Northwest should, for example, arbitrarily forego the use of electricity from coal-fired power plants if others also do not do so, since it could place the region at an economic disadvantage. It is difficult, however, to argue with the proposition that the region should take appropriate steps to ensure that it uses the most cost-effective sources of energy (including conservation). The region should not be trapped into heavy dependency on energy sources that in the future may be affected adversely by global warming (such as hydroelectric generation) or that may be subjected to Draconian regulation due to national or international concerns over the greenhouse effect (such as coal). Many of the speakers noted that flexible planning is the appropriate approach.

Following are summaries of the presentations made in the morning and afternoon sessions of the symposium.

1.1 SUMMARY OF PRESENTATIONS

Dr. John Harte - Global Warming: An Overview

Dr. Harte dealt with a variety of topics, including the available evidence on worldwide emissions of greenhouse gases to the atmosphere from fossil fuel burning and deforestation; concentrations of carbon dioxide and other trace gases in the atmosphere and the role of the oceans in modifying the rate of increase; the greenhouse mechanism itself and rate of climate change; attempts to verify the GCMs that forecast climate change; the consequences of climate change for temperature and precipitation; modifications and feedback effects inherent in earth-atmospheric interactions; and the uncertainties of estimating the timing and geographic distribution of climate change. Additional information was presented (in answers to questions from the audience) on the timing of manmade greenhouse effects as they interact with global processes.

According to evidence presented in the talk, fossil fuel consumption is one of two major sources of the increasing amounts of carbon dioxide in the atmosphere. There was a pause in the apparent trend in emissions from fossil-fuel burning in the 1970s, believed to be due to price-induced fuel conservation. The upward trend in consumption of fossil fuels (and greenhouse gas emissions) has now begun to reemerge, an observation that generated considerably more comment and passion in later talks during the day. Deforestation is an important secondary cause, with best estimates placing the contribution at about 20% of carbon dioxide emissions from fossil sources, although the net balance of carbon emissions from forest cutting and regrowth is not really known. Fossil-fuel emissions do not come primarily from any one source. Electric power production, transportation, industry, and space heating are all sufficiently significant that none can be ignored.

According to Dr. Harte, the evidence from ice core data covering the last 200 years suggests that carbon dioxide concentrations in the atmosphere have risen about 25% since 1800. The seasonal concentration varies regularly and inversely with the rate of photosynthesis in terrestrial plant life. Other greenhouse gases such as methane, nitrous oxide, and the chlorofluorocarbons are increasing even faster. Though fossil fuel production and combustion is a major source of methane, these gases largely are emitted by other human activities such as agriculture.

The greenhouse effect is a result of the fact that certain molecules, such as carbon dioxide and methane, absorb radiant energy in the "heat" or infrared part of the spectrum as solar energy absorbed by the earth is reradiated into space, a phenomenon discussed in more detail by Dr. Michael Schlesinger, who followed Dr. Harte on the program. Water vapor is a key gas in the warming process. Since the atmosphere can retain more water vapor as it warms, increases in temperature lead to increasing water vapor, which leads to still higher temperatures, a so-called positive feedback mechanism. This feedback mechanism is important enough, and its rate is uncertain enough, to cause considerable uncertainty in the estimated rate of increase of global warming. Other major uncertainties in the rate of global warming are caused by uncertainty in the future levels of human activity that result in emissions and the future rates of emissions, given those future levels of human activity.

Dr. Harte chose to discuss future global warming in terms of degrees per decade since many of the important effects of warming have to do with the rates at which plant, animal, and human life can adapt to climate change in comparison with the rate the climate is changing. In response to a question, Dr. Harte noted that the projected rate of change is fast enough that natural variations in solar output, earth orbit, and tilt of the earth's axis, which occur on time scales of thousands of years and would naturally cause global cooling, will not operate fast enough to counteract the impact of increasing carbon dioxide.

Much of the alarm over climate change has been the result of the predictions generated by GCMs. Dr. Harte discussed to the evidence available to verify that these big climate models are producing sensible results, a topic further discussed by Dr. Schlesinger. The first line of evidence is that the models, when applied to the more extreme conditions in the atmospheres of Venus and Mars, generate approximately the correct surface temperatures for those planets. A second line of evidence is that the earth's atmospheric carbon dioxide levels tended to be higher during those periods in the paleoclimate record when the earth was warmer. However, there is reason to believe in this case that past warm periods caused the increase in carbon dioxide rather than the other way around. Dr. Harte concluded that the evidence from paleoclimate may actually document a positive feedback effect of modest proportions rather than a verification of the GCMs. The third line of evidence cited by Dr. Harte was the steady warming of the world's atmosphere over the last 100 years, adjusted for such phenomena as the variations in solar output, incidents of volcanic eruptions (that tend to cause cooling), and similar events. The third line of evidence is controversial, he stated, because of problems of obtaining consistent temperature measurements over periods as long as a century.

The talk next turned to the effects of climate change, including temperature and precipitation. Although the individual human may not notice a 2° to 4° rise in temperature, the effects on of an increase in average temperature of this magnitude on ecosystems are very noticeable. To find a similarly warm period in the paleoclimate record, one has to go back nearly 65 million years to the Cretaceous-Tertiary Boundary, which had much different plant and animal life than currently exists. Similarly, the projected increase is greater than the change coming out of the last Ice Age. Precipitation impacts are much harder to forecast than temperature change, in part because we do not enough about clouds and storm formation. This leads to wide variation in precipitation forecasts from the various GCMs for particular regions.

The earth itself interacts with the atmosphere to modify the effects of climate change. For example, the warming of soils releases carbon dioxide, changes nutrient status, carbon dioxide uptake, and water utilization. In addition, phenomena such as acid rain can interact with climate change to magnify the initial effects. If warming of the atmosphere melts ice fields, the earth becomes darker and more absorbent of sunlight, which tends to reinforce the warming. Several examples of these feedback and mitigative processes were cited, to demonstrate the complexity and interconnectedness of the processes involved. Among these examples were summer fogs off the Northern California coast. These are caused by upwelling of cold ocean currents and wind patterns. Fog acts to cool the land and reduce forest fire hazard, while the upwelling brings up nutrients that support fish populations. If temperature changes, so do winds and currents, with unknown effects. These all contribute to the uncertainty of the effects of warming at a local level.

Finally, Dr. Harte mentioned that details of timing and geography can make an enormous difference in impacts. For example, a 15% increase in precipitation at the beginning and end of a dry summer month might have no influence on the incidence of forest fires, while an increase concentrated in the middle of the month could prevent fires or greatly reduce their intensity. Current computing power does not permit such predictions to be made.

In summary, while investigations to date have pretty well established a case for increases in global average temperature over the next 100 years unless global emissions of carbon dioxide and other greenhouse gases are drastically reduced, there is much to understand about the timing of the change, details of global processes, and effects of the changes. Much of the regional detail and understanding of feedback mechanisms remain highly controversial, and current computing power limits the ability to model much of the detail in time and space necessary to resolve policy issues.

Dr. Michael Schlesinger - The Greenhouse Effect: Theory or Fact

Dr. Michael Schlesinger's role in the symposium was to present information on the state of the art in forecasting the earth's climate and to discuss the state of knowledge concerning the timing of effects. He began with a fairly detailed review of the role carbon dioxide plays in global warming; delineated what is known about its rate of increase and the role of human activity in generating emissions; presented some forecasts of emissions; and discussed alternative ways in which these have been done. The section of Dr. Schlesinger's talk on the anthropomorphic sources of greenhouse gases in some ways repeated the information in Dr. Harte's talk, including data on the historical rates of increase of carbon dioxide and the other greenhouse gases and future rates of increase leading to an equivalent of doubled carbon dioxide sometime in the next century. One difference was that Dr. Schlesinger emphasized the fact that the United States currently accounts for only about 25% of the world's emissions and that the really large potential for increases lies in less developed countries (LDC) such as China or India. Rising per capita energy consumption in the LDCs represents a future source of emissions that is both outside the direct control of the developed world and difficult to negotiate from a position of higher per capita energy consumption when economic development is at stake.

The talk next turned to the effects of the greenhouse gases in the atmosphere. Here, Dr. Schlesinger vividly described the effects in terms of a planet with an atmosphere having only nitrogen and oxygen, versus one with nitrogen, oxygen, carbon dioxide (0.25%), water vapor, and ozone. The thin reradiation "blanket" of carbon dioxide, water vapor, and ozone increases the earth's average temperature by about 60°F and makes the planet habitable.

In forecasting climate change, Dr. Schlesinger contrasted his GCM approach with the historical climate analog approach being used in the Soviet Union. The temperature increases examined are similar for U.S. and Soviet researchers, but the conclusions reached are much different. By picking times when the world average climate was warmer, the Soviet researchers have the advantage of examining a situation with climate (weather) that actually happened. On the other hand, their climate changes result from unknown causes that would not necessarily be consistent with future climate change events. The GCM approach has the advantage that the mechanism underlying the models has been explicitly modeled, so the "cause" of a given change in climate can be identified. On the other hand, the forecasting model may not be giving a "true" result because the models are by nature simplifications of reality. One acknowledged problem with GCMs is that currently available computer equipment only permits computations to be done of temperature, precipitation, etc., on a geographic grid scale of 300 to 1,000 miles on a side. This means that, in general, GCMs do not appear to give reliable forecasts of climate on less than a continental scale, while all the interesting climate impact issues exist at a much smaller geographic scale.

An apparent solution to the geographical resolution problem is to reduce the size of the grid rectangles in the GCMs from 300 miles on a side to something much smaller. However, because weather systems and other atmospheric phenomena take less time to pass through a smaller grid box, time scales must also be reduced. This means that to reduce grid resolution by a factor of 10, the computer must be 1,000 times faster than the fastest computer currently available.

Dr. Schlesinger then turned to GCM model results to illustrate what these models are able to tell us about future world climate. While the models differ for reasons their creators believe they understand, the five extant GCMs agree on results of between 2.8° and 5.2°C warming for a doubling of the carbon dioxide concentration in the atmosphere, in equilibrium. (In fact, doubling would not occur instantaneously, nor would concentrations necessarily cease to grow once doubling is achieved, a point of great significance to policy makers concerned with how much time is available for policies to be decided upon, to be implemented, and to work.) The warmer the predicted climate, the less sensitive to carbon dioxide uptake the models seem to be. This effect is due to the melting of sea ice. While the models agree qualitatively that there would be cooling of the stratosphere and more warming of the troposphere toward the poles, quantitatively they disagree significantly on the degree of temperature increase. The models disagree even more fundamentally on changes in precipitation related phenomena such as soil moisture at the regional level.

Finally, the talk covered nonequilibrium change and a dilemma for policy makers. This part of the talk began with a discussion of temperature increases during the last 100 years, which has been perhaps 0.5° to 0.6°C. Based on the simulation of carbon dioxide increases for this period, the GCMs project that the temperature should have increased by 1.1°C in equilibrium. This leads to one of two conclusions. Either the models are twice as sensitive to carbon dioxide increases as they should be, or as the modelers believe is actually the case, nature has not yet come to equilibrium with higher carbon dioxide concentrations. The critical question if the modelers are right is: how long does it take to achieve an equilibrium climate? If the delay due to ocean dynamics is about 50 to 60 years, as Dr. Schlesinger believes is most likely based on his calculations, then the effect of a given increase in atmospheric concentrations will be seen well after it is too late to prevent it--what Dr. Schlesinger called the detection-mitigation dilemma. If the models are right, even if carbon dioxide levels could be stabilized at today's level, significant warming could still be expected. However, Dr. Schlesinger noted that the actual path of temperature increase is quite complex.

As a final policy prescription, Dr. Schlesinger noted that, in view of the uncertainty, two actions make sense. The first is to accelerate the pace of physical climate research in an effort to decrease the uncertainty of our understanding of the complex climate system. The second is to perform assessments of long-lived projects under the assumption of both changed future climate and constant future climate, and to begin to examine the consequences of being right or wrong about the future in each case. This was a theme picked up by various speakers during the day (especially Mr. Dick Watson of the Washington State Energy Office) as a means to deal with the pervasive and perhaps uncontrollable uncertainty pervading the climate change problem.

Dr. Dennis Lettenmaier - Effect of Global Warming on Pacific Northwest Hydrology

Dr. Lettenmaier's talk largely concerned a study he performed in California for the EPA, and its implications for Pacific Northwest hydrology. Management of the Pacific Northwest electric power generation and irrigation systems, and sport, commercial, and Indian fisheries management plans all are based between on about 50 to 100 years of hydrological records and a fundamental assumption of stationary climate (that is, a climate with no major trends in temperature or precipitation) and, therefore, stationary average hydrology. Dr. Lettenmaier's work for EPA examined the impact of 3.5°C warmer temperatures forecasted by three GCMs at doubled carbon dioxide for California and analyzed the impact on four small "representative" river subbasins in the Sacramento-San Joaquin drainage. Snow accumulation in the winter and spring runoff currently dominates in both California and in the Pacific Northwest, but Dr. Lettenmaier found that, under elevated temperatures forecasted to prevail in his four California subbasins, winter snowfall was largely replaced by winter rainfall, which changed the seasonal pattern of discharge toward more winter runoff and very low summer flows. The analysis was then extended to the Sacramento-San Joaquin system as a whole and a reservoir operations model was used to estimate the effects on flood frequency, irrigation and water deliveries, reservoir levels, and San Francisco Bay estuarine ecology.

Like the Pacific Northwest, the Sacramento-San Joaquin Rivers have storage reservoirs designed to control within-year runoff based on snowpack rather than multiple-year storage. The California system-wide analysis showed major increases in floods associated with rain-caused runoff, very low September storage figures, and substantial decreases in the amount of water that could be reliably delivered to the state water projects. The implications for the Pacific Northwest are significant. Because Pacific Northwest reservoirs are at lower elevations than most of the California reservoirs, the effects on snowpack versus rain may be even more severe. Analysis is proceeding on a subbasin of the Yakima River to verify these speculations. If Dr. Lettenmaier's new study confirms these findings, changes may be required in the way in which the Pacific Northwest hydroelectric and irrigation systems are operated.

Dr. Duane Neitzel - Impact of Global Warming on Anadromous Fisheries of the Pacific Northwest

Dr. Duane Neitzel ended the morning discussion with a talk on the possible impacts of climate change on salmon and steelhead in the Pacific Northwest. This is a particularly important topic because of the large commitments of resources being made to the Power Council's Fish and Wildlife Program. Underlying this investment of resources is an implicit assumption that the changes in the climate of the Pacific Northwest will not alter the effect of the fish and wildlife mitigation actions now being undertaken. However, Dr. Neitzel pointed out three lines of disturbing evidence that suggest that this assumption may not be true. The first is that groundwater eventually takes on the average temperature of the atmosphere and that its temperature at shallow depths changes with the changing of the seasons. In many of the smaller, warmer tributaries in the Pacific Northwest, cold groundwater provides part of the water flow and protects juvenile salmon from heat stress in the summer. Loss of this protection could restrict the rearing environment in the Pacific Northwest and undermine the Power Council's program of upstream mitigation.

The second piece of disturbing evidence is that the paleoclimate record for the last 10,000 years shows the Pacific Northwest to be significantly drier when it is warmer. About 6,000 years ago, during the mid-Holocene period, the Pacific Northwest was about 2°C warmer than it is today. During that period, there was considerably less average annual precipitation. If lower precipitation became the norm in the Pacific Northwest, conflicts between water for power and irrigation versus in-stream uses would become more severe. Moreover, the mid-Holocene archaeological record on human encampments shows that salmon and steelhead were in very low abundance during this warmer period.

Finally, life history and environmental evidence on salmonids and other species reinforces the physical evidence presented above and suggests that warmer water competitors may thrive at the expense of salmon and steelhead, which are cold-water species. In summary, Dr. Neitzel suggests that climate change may force the Power Council and the region's fish and wildlife agencies to rethink their current strategies for fish and wildlife mitigation, divorcing them from dependence on an unchanged climate regime.

Dr. Gordon MacDonald - Greenhouse Gases and Electric Power Resources

Dr. MacDonald devoted his talk to the electric power industry, its relative role in emissions of greenhouse gases, and policy issues that surround control of these emissions. The talk began with another version of the rising emissions curve covering the last 130 years, showing 4.4% to be the usual annual rate of growth in carbon dioxide emissions, with exceptions during World War I, the Great Depression, World War II, and the Arab oil embargo in the 1970s. Much of this growth used to be in oil, but coal use is currently growing at 5% per year. Coal, besides being the fossil fuel increasing fastest in popularity (especially in the centrally planned economies), produces almost twice the carbon dioxide per unit of energy as does natural gas. Converting coal to synthetic fuel only makes the situation relatively worse. For example, while methanol when burned emits only about 1.5 times as much carbon dioxide as does natural gas, so much fuel is used in making methanol from coal that the methanol process results in about 3 times the carbon dioxide emitted per unit of energy delivered.

The United States, said Dr. MacDonald, accounts for slightly more than one fifth (1.4 out of 5.5 gigatons carbon) of the world's anthropogenic emissions of carbon dioxide. The largest single source in the United States are electric utilities, and electric utilities are a relatively larger source worldwide. Promising technologies for reducing utility emissions include more efficient use of electric energy to reduce the requirements for generation, and relatively more generation via hydropower, solar, nuclear, and gas combined-cycle technologies. Dr. MacDonald made the point that the most efficient new combined-cycle gas-fired technologies have a thermal-to-electric efficiency of about 43% and emit a little over half as much carbon per kilowatt hour as a new coal-fired or oil-fired powerplant. In Dr. MacDonald's opinion, natural gas must be used more effectively throughout the energy economy, while unconventional natural gas resources such as hydrates make natural gas abundant enough in the United States to make a gas-fired strategy viable. For the long run, he said, nuclear power generation must be included in the set of options. In response to questions, Dr. MacDonald stated that he is an advocate of carbon emissions taxes as a means to improve efficiency of combustion and utilization of energy. Coal would increase in cost by about 50% if carbon were taxed at about one cent per kilogram.

Although Dr. MacDonald did not go into much detail on the other greenhouse gases, he opined that total chlorofluorocarbon phaseout must not only be applied to the industrialized world, but also to the developing world. He felt that enforcement of ozone and carbon monoxide emissions standards is an important part of control of the greenhouse effects of these gases. He acknowledged the difficulty of controlling methane, but did not mention any of the nitrogen compounds that produce greenhouse effects.

Mr. Dick Watson - Regional Culprits: Sources of Greenhouse Gases

Mr. Dick Watson of the Washington State Energy Office was to address the topic of regional sources of greenhouse gas emissions to provide the Power Council a perspective on how the region differed from the country as a whole. He departed slightly from this charge in that he concentrated on the State of Washington (for which he believed he had better data) and went beyond descriptions to policy recommendations.

The talk began with general background on national sources and trends of carbon dioxide emissions and reiterated Dr. MacDonald's points about gas technologies being low emitters of carbon dioxide. Turning to the Pacific Northwest, Washington data on carbon emissions show a sharp increase in the early 1970s, when the Centralia coal-fired power plant came on line. There was then a conservation-related pause during the 1970s and a subsequent increase due to increased use of petroleum (probably in transportation). Washington, similar to other Pacific Northwest states, uses very little coal. It therefore contributes relatively little carbon dioxide per person and emits a very small part, though not a part that can be ignored, of the national total (1% of North America's total). Transportation is the major contributor in Washington (48%), with industrial emissions second (24%), and commercial and residential sectors tied for third with electrical utilities (14% each).

Mr. Watson went on to discuss policy options for reducing emissions. One option was to scrub greenhouse gases from exhaust gases, which is expensive and creates its own waste problems. Interestingly enough, this was one of the very few times during the day when removal technologies were even mentioned. No speaker discussed these technologies in any depth. Mr. Watson joined the other speakers in advocating increased energy efficiency as a more cost-effective option. A third option was the use of alternative fuels, such as natural gas and renewables. Finally, he left nuclear energy as an option, although one that he stated needs a lot of work. However, Mr. Watson concentrated his comments on energy efficiency and alternative fuels, their potential for reducing emissions, and the feasibility of their use.

As a potential target for reducing emissions, Mr. Watson examined a reduction of 20% from 1985 levels of emissions by 1990. Between 1972 and 1985, the amount of energy used per dollar of gross state product has decreased by 2.2% per year with what he characterized as a "relatively minor effort." For a 20% reduction within 5 years, this would have to be increased to 4% per year, which he believes to be within the realm of possibility. (Absolute reductions of 20% in a growing economy would have to be greater, and a late start would also require a higher rate of saving.) The strategy had two parts. In the short term, Mr. Watson recommended conservation and some fuel switching. For the longer term, he recommended a foundation of energy efficiency, renewables, and improved nuclear systems if the issues of cost, safety, and waste can be addressed successfully. In the short term for transportation, he recommended increasing the utilization rate of automobiles from 1.1 to 2.0 passengers per vehicle through better use of buses, van pools, and light commuter rail in the urban areas. He also recommended work on increasing automotive fuel efficiency. Natural gas was mentioned as a fuel for fleet vehicles and buses in urban areas. In industry and in commercial and residential buildings, extensive conservation was described as possible, and some cost-effective examples from Washington Energy Office and Bonneville Power Administration (BPA) experience were given.

Summarizing the effects of conservation, Mr. Watson showed figures on the mix of Pacific Northwest generating technologies with and without full implementation of the Power Council's Regional Energy Plan. These conservation technologies can be demonstrated to be cost effective; however, Mr. Watson pointed out that there are many market barriers and that implementing the Regional Energy Plan will not necessarily be easy.

As guidance to policy, Mr. Watson noted that the least-cost framework that the Power Council uses for resource planning should be extended to include a least-carbon framework as well. He did not address whether a mechanism should exist to balance the environmental costs and benefits associated with least-carbon planning against costs associated with least-cost planning, and how such a mechanism might work. The other components of his policy guidance included Dr. MacDonald's carbon tax, greater efficiency standards on cars, appliances, and buildings, renewed weatherization efforts, research and development on renewables, and a nuclear option improved with respect to cost, safety, and waste.

The most important part of the policy guidance portion of the talk dealt with the consequences of having the right or wrong policy if climate changed or if it did not. If climate does not change and energy efficiency (for example) is vigorously pursued, society still benefits from a cleaner environment and reduced cost of energy. If the climate does change, the mitigation costs will have been reduced and, to some degree, the onset of the change will have been delayed. If, on the other hand, the climate changes and no action to prevent the change has been taken, society runs the risk of high adjustment costs and obtains none of the ancillary benefits. Mr. Watson concluded by advocating increased efficiency as a win-win situation, a point reiterated more strongly by speakers that followed him on the agenda.

Dr. Peter Beedlow - Regional Research Needs

Dr. Peter Beedlow of the EPA Corvallis Laboratory discussed the EPA research program in global climate change. Unlike EPA's traditional fate-and-effects, end-of-pipe studies, the longer term studies in this program are directed at understanding the human and nonhuman mechanisms of global warming in producing climate effects, as well as determining where the problems are and what might be done to ameliorate them. As distinguished from the National Science Foundation (NSF) approach, however, the research is policy driven. The EPA's primary responsibilities with the National Climate Research Program include answering questions and formulating policy concerning emissions and supporting several areas of research, particularly hydrology and ecological effects. An important assumption underlying the EPA research is that the global warming impacts will show up at the regional level and are likely to change dramatically from region to region.

Dr. Beedlow spent a portion of his talk outlining several of the significant uncertainties underlying global change effects. One that was not mentioned by the other speakers was that global warming could melt Arctic permafrost areas, possibly releasing large amounts of methane to the atmosphere and compounding the global greenhouse effect. Areas of research within the EPA plan include determining fluxes of greenhouse gases to the atmosphere and feedbacks from climate change that may affect emission rates; regional hydrologic and ecological effects of climate change; and support for other agencies' efforts in atmospheric chemistry and physics. The initial research will concern emission factors (rates of trace gas emissions from various sources) and regional ecological sensitivities. The Pacific Northwest is an interesting place to study effects because it contains most of the types of ecological resources that potentially could be affected--agriculture (both dry land and irrigated); hydroelectric and thermal power production; estuaries that could be affected by sea level rise; forest production; and fisheries.

Mr. Ralph Cavanagh - The Role of Energy Efficiency

Mr. Cavanagh's role in the symposium was to summarize the possible role that energy efficiency could play in ameliorating the greenhouse effect. The talk was actually broader than that and encompassed the general topic of efficiency as a beneficial and cost-effective use of resources in its own right, regardless of the effect on greenhouse gas emissions. He then went on to discuss several policy prescriptions specific to the Pacific Northwest situation.

The starting point for Mr. Cavanagh's talk was that conservation of energy does not mean doing without high-quality, adequate energy services. The Power Council's work, he said, clearly shows that the level and quality of energy services are largely independent of the level of energy consumption. The greenhouse effect is yet another reason, he said, to mourn the lack of national progress on energy conservation. For example, although it happened that between 1973 and 1986, gross national product increased by 30% while energy use remained constant, in the first eight months of 1988 the use of coal increased by 10% over 1986 values. One symptom of the lack of federal leadership on conservation was reflected in the decisions during the 1980s to roll back automobile efficiency standards and to not seek efficiency standards for appliances. Similarly, he noted, the Council on Environmental Quality (CEQ) withdrew proposed guidance to federal agencies on assessing the impact of major new federal initiatives on the greenhouse effect. Mr. Cavanagh did not go into the merits of these individual policies but cited them as general evidence of the lack of federal concern.

Mr. Cavanagh next turned to Pacific Northwest energy policy, saying that it had some unique things to teach the rest of the country, but still had some room for improvement. One important thing that the Pacific Northwest has learned is that energy consumption growth is not destiny, and that it is something that could be influenced with appropriate planning and actions stemming from that planning. There are, however, policies that could be implemented in the Pacific Northwest that have not been and that could contribute to reducing the greenhouse effect. More important, they are cost effective and environmentally desirable for other reasons. The first action on his list was enacting the Power Council's Model Conservation Standards for residential buildings as part of the Washington State building code in an effort to increase the percentage of houses built in the region that meet the Power Council's standards. The second action was to improve commercial building standards. Mr. Cavanagh stated that, although the commercial sector is the most rapidly growing sector for energy consumption, the Power Council's "consensus" commercial standards adopted in 1980 could be considerably strengthened and improved. The third action was regulatory reform that would prevent electric utilities from automatically losing profits when sales volume is reduced due to conservation investments they make. He did not propose any specific reform, but advocated that representatives from the four Pacific Northwest states meet to consider ways in which to reward utilities for quality of service rather than amount of energy sold.

Two other policies that were advocated during the course of the talk related to power planning and resource acquisition in the Pacific Northwest. He recommended that with thermal power plants, estimated future likely cost of regulatory compliance for the limitation of carbon dioxide emissions ought to be included. Finally, he advocated that power generators and conservers be treated on an absolutely equal footing in an auction process for the acquisition of energy resources, including paying conservers as well as generators.

Mr. Michael Totten - The Global Warming Prevention Act

Mr. Michael Totten's role in the conference was to discuss federal initiatives that deal with global climate change. Mr. Totten began with a discussion of several of the symptoms of global environmental degradation and the costs and losses (identified in the EPA report to Congress) if no action is taken. The challenge, he stated, is to take those actions that spur economic prosperity without generating dangerous levels of greenhouse gases. This is best done by taking those actions that tie-in by solving other problems or providing multiple benefits. Available options range in cost by a factor of 10 or more; therefore, the options for reducing greenhouse emissions need to be ranked in cost-effective order using least-cost energy planning. Cost-effective energy efficiency, he stated, has provided numerous economic benefits to the United States over the past 15 years, including savings to the economy of $160 billion per year. Continued milking of the efficiency "cash cow," said Mr. Totten, could result in a decline in oil consumption, a decline in carbon emissions, no net additions to requirements for nuclear power plants, and a better guarantee of meeting both domestic and world-wide human needs.

He then narrowed the scope of his discussion to a series of specific initiatives and then discussed a number of specific technologies and approaches to reduce greenhouse emissions that could benefit from federal development support or federal policy toward implementation. The technologies discussed included compact fluorescent lamps, daylighting, imaging specular reflectors, improved windows, high-efficiency refrigerators, promising high-efficiency automobiles, industrial materials recycling, improved cooking stoves for developing countries, tree planting, renewable energy, advanced turbines, and biofuels. He concluded his talk with some general points about national energy policy.

The energy technologies Mr. Totten discussed are generally considered to be already available technology. The compact fluorescent lamp, which uses 75% less electricity than the incandescent lamp it replaces and also reduces nonenergy maintenance costs, is in commercial production. Commercial building daylighting provides a significant amount of light and heat energy in buildings where it has been adopted. Imaging specular reflectors cut in half the number of fluorescent tubes required in commercial buildings. Window improvements developed in the late 1970s are in commercial production, although federal funding for even more advanced designs has been curtailed. Refrigerators using 90% less electricity than conventional refrigerators have been marketed on a limited basis for geographically remote situations. Although they currently cost three times as much as conventional models, the designer believes the price would drop to that of a conventional refrigerator with mass production. Vehicles that are now subcompact prototypes or in production in Europe and Japan can get as much as 135 miles per gallon, but technologies are available that permit larger cars to get 80 miles per gallon. Simple stove technologies exist that quadruple the efficiencies of conventional stone fires used for cooking in much of the developing world. In the Los Angeles area, planting trees around buildings has been found to reduce energy consumption in the building by 40% to 50%.

Mr. Totten also believed that renewables and biofuels can make a much greater contribution to energy production in the United States. (Renewables currently provide 10% of the energy used in this country; most of this is hydroelectric power.) One factor that would contribute to the future of biofuels is the use of very-high-efficiency jet engines employing intercooled steam-injected gas turbine technology in place of today's more conventional combustion turbines and combined-cycle units. The theoretical potential of such technologies in developing countries is also great.

While the demonstrated and theoretical potential of these and other technologies mentioned in the talk are great, public policy has not kept pace with developments in Mr. Totten's opinion. Inappropriate market signals pose a major barrier to cost-effective investments, while institutional rigidity discourages efficiency investments by individual consumers of energy, especially renters, persons on fixed incomes, and cash-poor companies. The cost-effectiveness figures, says Mr. Totten, show that priorities are reversed. Energy producers in the United States and elsewhere receive lavish subsidies, amounting to perhaps $40 billion per year in this country. Energy-efficiency research has declined by 75% in the last 8 years while the total DOE budget has increased. Mr. Totten believes it imperative that the country establish comprehensive least-cost energy planning, adopt more environmentally benign resources, support energy-efficiency research and development, and improve motor vehicle fuel economy mandates (backed by "gas-guzzler" taxes and resources in fiscally constrained times.

1.2 SUMMARY OF THE SYMPOSIUM

The various speakers gave the audience much food for thought. The speakers in the morning session showed that, despite great advances in scientific understanding of our global climate system, there is still much that we do not know about the causes, progress, or effects of greenhouse-gas-induced global warming. From a policy perspective, the issue is difficult because we may not know whether greenhouse-gas-induced warming is actually occurring until it is too far advanced to prevent. The afternoon speakers provided a pathway of action in the face of the great uncertainty we face and the admittedly small role the Pacific Northwest plays in what is truly a global problem: do those actions that are cost effective for other reasons; that save energy and money; and that reduce the negative environmental consequences of human activity. These actions will in most cases also reduce the impact of global warming.

There was a second action identified that received less emphasis in the workshop, but may be equally if not more important should the world community be either unable or unwilling to halt global warming. If the speakers in the morning session were right about the lag times between policy and the response of the world's climate, then it appears some warming may be inevitable. If that is the case, the Pacific Northwest, with its heavy dependence on natural resource related industries, should begin to do climate contingency planning for the use of water in its rivers, for its forests, and for its other natural resources that may be affected by warming. Actions are being taken now on the assumption of an unchanged climate that may well have adverse consequences in the next century should the climate change. It may or may not be too soon to act. It is not too soon to think and to plan.

2.0 INTRODUCTORY REMARKS

Tom Trulove, Chairman
Northwest Power Planning Council
Portland, Oregon

We are here today to talk about the greenhouse effect and global warming. We have just experienced a week when we had a substantial arctic blast with high winds and low temperatures, and one of the records that was broken all across the state and the region was wind chill factor. Temperatures were not necessarily lower than they have ever been in the past, but the wind chill factors certainly were. Most of the plants that were left outside are all freeze-dried now along with nearly everything else that we owned, so this is a great time to talk about the greenhouse effect. In fact, with the glacier that is forming in the parking lot, I do not know how much more of this greenhouse effect we can stand. But those in the know tell me this recent weather is a short-term phenomenon.

In introducing the seminar, perhaps the thoughts that I had were best stated by David Freeman, the former Managing Director and Chairman of the Board of the Tennessee Valley Authority, in an article that recently appeared in the *Electricity Journal*. In his article, which was entitled "Leadership Role of the Electric Utilities," David Freeman observed:

> "I am not a doom sayer by nature, and do not believe that we face a choice between an unlivable climate and freezing in the dark. I do believe that our quality of life can be sustained and improved with a dramatically lower level of energy consumption."

He went on to say:

> "One key to sustaining improving the quality of life on this earth, is to face up to the threat of climate change in a timely fashion."

The nature of the problem was probably best stated by Edmond Burke a couple of centuries ago when he wrote:

> "The public interest requires doing today those things that men of intelligence and good will would wish 5 or 10 years hence had been done."

Freeman goes on to say:

> "The plain truth is that there is no absolute proof of climate change from the buildup of carbon dioxide and there may be none short of seeing a catastrophe unfold. The issue is not whether there is proof positive--that is a suicidal test--but whether there is sufficient evidence of the risk to suggest that society dare not run that risk."

Well, it is precisely that risk that we attempting to assess here today with the help of some of the world's leading experts in a variety of topics. There is a lot of uncertainty as there is in almost everything that we have to deal with in life. I might say that I believe the Power Council is ahead of the learning curve on this issue. Our emphasis on energy efficiency and conservation is certainly one of the most effective strategies for dealing with the situation whether or not the greenhouse effect and global warming are realities.

We need to learn what are the likely effects that will have some bearing on our power planning. What does all of this mean for the future of thermal resources fired by fossil fuel? What does it mean for nuclear technologies and the various renewable resources? Clearly, we in the Northwest are not going to solve this problem. We do not rely and probably will not rely on fossil fuels. We all know also that transportation equipment is probably the number one emitter of carbon dioxide in this society. However, greenhouse concerns and strategies may well affect the costs, reliability, and availability of many of the currently popular resource alternatives.

Our resource mix and the cost of electricity to the Pacific Northwest could well be affected. We need to be prepared to honestly and objectively evaluate the significance of the greenhouse threat. Just as clear and certain, but not less important, is our social responsibility. For it is incumbent upon us here today to act so as to leave our children a heritage for which we will receive their blessing and not their curse. Ultimately, it is not what we have that can make us a great region or nation, but how we use it. It is how we use the advantages we have in the environment with which we are blessed.

So, having said that, join with us as we explore the facts and issues surrounding the greenhouse effect and global warming, and more importantly participate with us over the next few months as we struggle to devise a reasonable and responsible public policy approach for the electric industry in the Pacific Northwest.

3.0 GLOBAL WARMING: AN OVERVIEW

John Harte, University of California
Berkeley, California

3.1 INTRODUCTION

It is a real pleasure to be here. I am especially pleased to see an old friend--Gordon MacDonald--on the speakers list today. It was Gordon who 20 years ago had the foresight and initiative to organize a National Academy of Sciences (NAS) study to look at the environmental hazards of a proposed airport in the Everglades. That study proved to be extremely exciting and led me out of theoretical physics and into a career in interdisciplinary research on environmental problems.

Climatologists used to enjoy beginning talks on climate change by turning Mark Twain upside down and saying, ". . . everybody is doing something about the weather, but nobody is talking about it. . . ." And indeed, that was the case up until a few months ago. But last summer, a series of events occurred that brought climate warming into the forefront of the public's attention. There were, of course, the heat waves of the summer and the droughts that have occurred sporadically and around the country over the last several years. And then there were the hearings that Senator Tim Wirth conducted early in the summer, which focused considerable media attention on the idea that we are perhaps already seeing the first signs of global warming caused by the greenhouse effect. Since then, in the last 6 months, there have been numerous conferences, workshops, and hearings, and researchers around the world are turning their attention at an increasing pace to the climate problem. All this attention is wonderful to see, because global warming is a very important problem.

In these opening comments I wish to give you a very broad summary of the whole problem. I know a lot of interesting things will be said about the potential for energy conservation as a means of alleviating the problem, so I am not going to discuss that topic. I am going to emphasize in my comments, the distinctions among the things we feel quite certain about, the things we are pretty sure about but for which there is still good honest debate and the need for more research, and the things about which we are almost entirely in the dark. I want to take this approach because in a field of study as complex as climate warming, which includes many researchers in different scientific disciplines, huge amounts of data, and many tested and untested theories, it is very easy to get confused about what is scientific "fact", what is a hunch, and what is just pure unadulterated hogwash.

3.2 EMISSIONS FROM FOSSIL FUELS

Figure 3.1 depicts worldwide carbon dioxide emissions from fossil-fuel consumption. Fossil-fuel consumption is the larger of the two major sources of the increasing amounts of carbon dioxide in the atmosphere. The figure contains a breakdown from 1950 into the mid-1980s of the total fossil-fuel sources of carbon dioxide from liquid fuels (petroleum), solid fuels (coal), and gaseous fuels (natural gas). The units used in Figure 3.1 are gigatons (billions of tons) of carbon.

The amounts of carbon dioxide coming from these three categories of fuels might mislead you into thinking that is how much of each of those fuels we burn. However, that is not the case. When it is burned, natural gas produces about 35% less carbon dioxide per unit of energy than does petroleum, and petroleum, in turn, produces about 15% less carbon dioxide than coal. So the actual amount of gaseous fuel used is higher in proportion to the use of the other fuels than Figure 3.1 would indicate.

One of the interesting features of Figure 3.1 is that we see the end of a trend that started in the 1970s, when carbon dioxide emissions leveled off somewhat. Of course, that was the result of a sequence of events that started in 1973. Some of this leveling off was due to price-induced reduction in consumption (for example, driving less or during the thermostat down), and some of it was due to the increasing efficiency of our energy-consuming gadgets. Unfortunately, there has recently been an upturn in

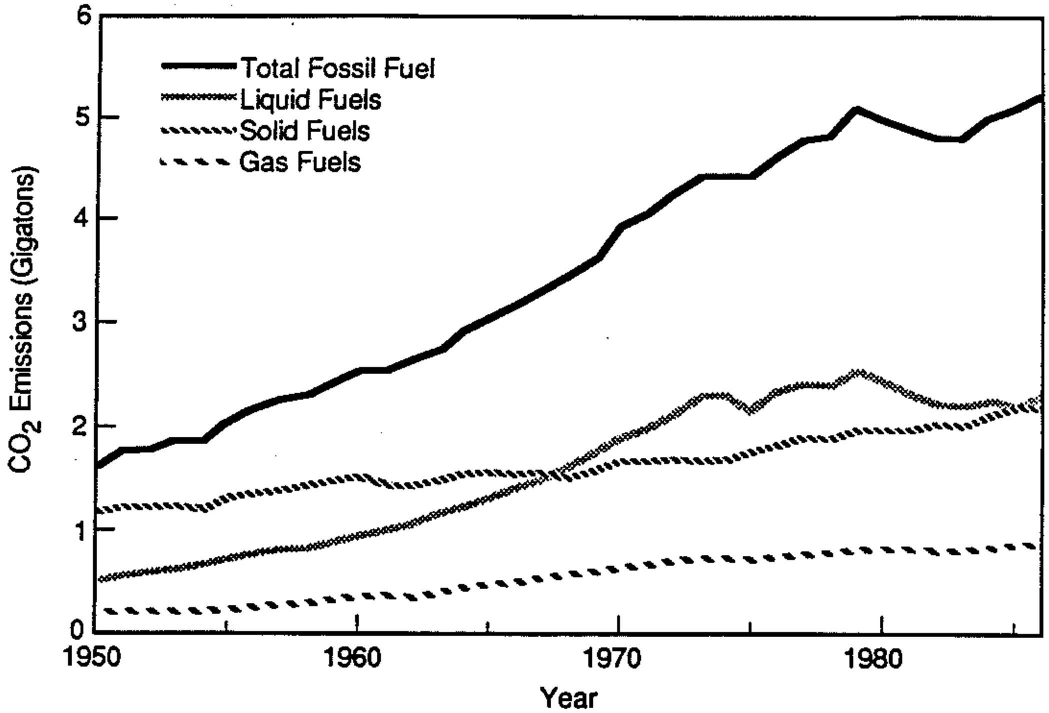

Figure 3.1. Annual Carbon Dioxide Emissions from Fossil Fuels, 1950 to 1986

the trend, and the question is whether that upturn will continue and put us back on our old track, or whether we will be able to bring about another leveling off and possibly a reduction in fossil-fuel consumption and, therefore, carbon dioxide production. That is a major issue that I hope will be discussed during this symposium.

3.3 DEFORESTATION

The other major source of carbon dioxide emission to the atmosphere comes from deforestation. I would like to show you a graph of how much deforestation has occurred over the years--I can hardly do that because it is very uncertain--but instead, consider a typical deforested hill slope in the tropics. Typically, large land areas in the tropics have been deforested to provide more land for cattle grazing. Interestingly, in some of these areas, the amount of rainfall has decreased. Many people think, although it is still speculation at this time, that the loss of the forest cover has affected the local climatic conditions.

The amount of carbon dioxide emitted to the atmosphere each year as a result of deforestation is a subject of much controversy. During their normal life, trees take in carbon dioxide from the atmosphere, and then when they decompose, the carbon dioxide is returned to the air. This is a closed cycle. When we deforest a hill slope, we remove the carbon that is stored in those trees. When those trees or the products they are made into decompose, their carbon is not reused by new trees, so there is a net addition to the atmosphere of carbon dioxide from deforestation. It is estimated that, worldwide, an area roughly the size of the state of Pennsylvania is deforested each year. That estimate could be 50% too high or too low, but even if we knew how much land is deforested, we still wouldn't know how much the biosphere contributes to carbon dioxide emissions. The reason is that through much of the temperate zone, forests are growing healthily. In New England, for example, there is more forested land now than there was 100 years ago, because many formerly cropped areas are now returning to forest land. We do not really know what the net balance of carbon is from forest clearing and forest regrowth.

The increase in carbon dioxide in the atmosphere also acts as a stimulant to vegetation, but again, we do not know how important this mechanism is. Also, we do not know to what extent soils are a net source or sink for carbon.

In my judgment, the best estimates today are that about 20% of the additions of carbon dioxide to the atmosphere come from the biosphere, although until a few years ago, the biosphere was widely believed to be a much larger source.

3.4 CARBON DIOXIDE IN THE ATMOSPHERE

Over the years, the effect of fossil-fuel burning and deforestation are cumulative, causing an increase in the carbon dioxide levels in the atmosphere. In the left middle panel of Figure 3.2, the ellipses are ice-core data showing this buildup. It turns out that if you look at the Greenland ice shelf and associate a date with a particular stratum in the ice core, you can then look at the chemistry and determine how much carbon dioxide was in the atmosphere at the time each little increment of ice layer was formed. The reason is that carbon dioxide in precipitation is in balance with the carbon dioxide in the atmosphere, so that when the water freezes, the ice traps the carbon dioxide and preserves, in the ice, a record of what was in the atmosphere at that time. So by looking at the ice core data from the year 1800 on to the present, we find evidence that suggests that there has been a steady increase in atmospheric carbon dioxide. The units here are parts per million--in the year 1800 about 280 millionths of the atmosphere was carbon dioxide. Today, the number is about 350 million. So the amount of carbon dioxide has increased by about 25%.

The ice-core data can be questioned because there are always uncertainties when indirect measurements are used, but fortunately we have a more recent detailed set of very accurate measurements conducted in real time in the atmosphere (right middle panel, Figure 3.2). The data are from Mauna Loa in Hawaii and have been gathered by Charles Keeling since the late 1950s. The ice core data are in good agreement with the more recent, and more accurate measurements, and that gives us confidence that the ice core data are probably correct. So we can conclude that there has been a 25% increase in atmospheric carbon dioxide during the past 200 years.

In Figure 3.3, the carbon dioxide levels in the atmosphere are shown as a function of latitude. In the Northern Hemisphere you see a strong cycle in the record. It is an annual cycle in the carbon dioxide level in the atmosphere, and it occurs because the biosphere (mainly the forests) take in carbon dioxide during the growing season, which is in the spring and summer in the Northern Hemisphere. During the nongrowing season, the biosphere returns carbon dioxide to the atmosphere in the course of decomposition and respiration. So, when the carbon dioxide level is high, you are looking at a period when photosynthesis is at a low, and when the level of carbon dioxide is low, you are looking at the height of the growing season, when the atmosphere is temporarily deprived of some of its carbon dioxide because of the uptake by plants.

In the Southern Hemisphere, we see a much weaker cycle because there is much less forested land in the Southern Hemisphere than in the Northern Hemisphere. As would be expected, the cycle in the Southern Hemisphere is 6 months out of phase with the cycle in the Northern Hemisphere. The highs occur in the Southern Hemisphere when the Northern Hemisphere is at a low. This gives us confidence that we really understand the carbon system. If we did not see this type of cycle, we would be concerned.

3.5 OTHER TRACE GASES

Figure 3.2 also shows the buildup in the atmosphere of two other gases. Methane is at the top and nitrous oxide at the bottom. Like carbon dioxide, they are called greenhouse gases because in the atmosphere their climatic effect is qualitatively similar to that of carbon dioxide. The rates of increase of these gases are different than for carbon dioxide and they have different sources. The most significant sources of methane are rice paddies and cattle raising operations, while nitrous oxide originates from fertilizer use and fossil-fuel burning. Chlorofluorocarbons are also greenhouse gases. Many nations in the world have agreed to phase out

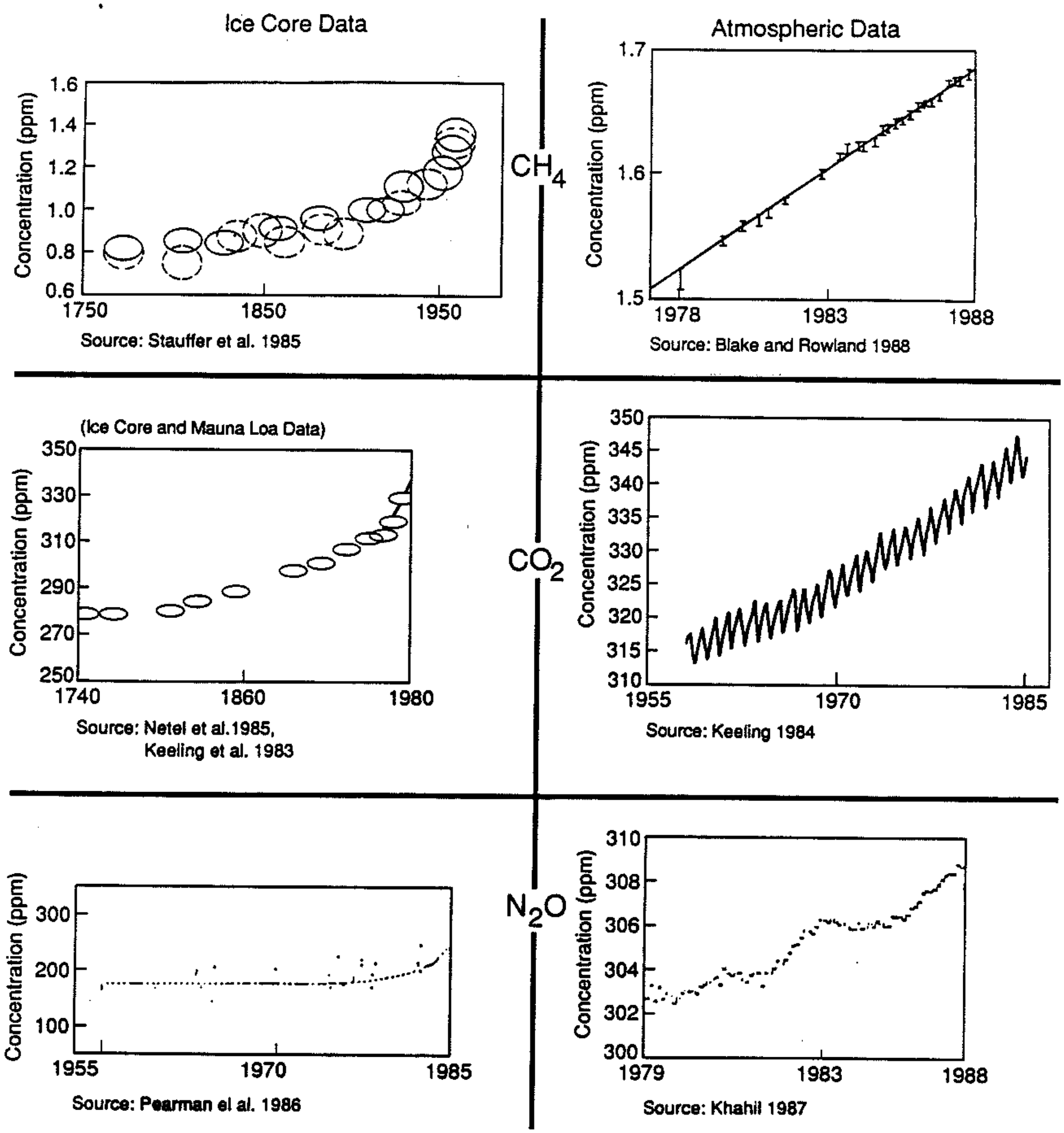

Figure 3.2. Concentrations of Trace Gases from Ice Cores and Atmospheric Samples

the use of chlorofluorocarbons, not because of their role in climate change but mainly because of their role in destroying the stratospheric ozone layer. However, another benefit that would result from chlorofluorocarbon control is that the greenhouse problem would be reduced. The rates of increase in the atmosphere of trace gases other than carbon dioxide are generally greater than the rate of increase of carbon dioxide; by the middle of the next century, these other trace gases are likely to contribute more than half the total effective greenhouse gas increase in the atmosphere.

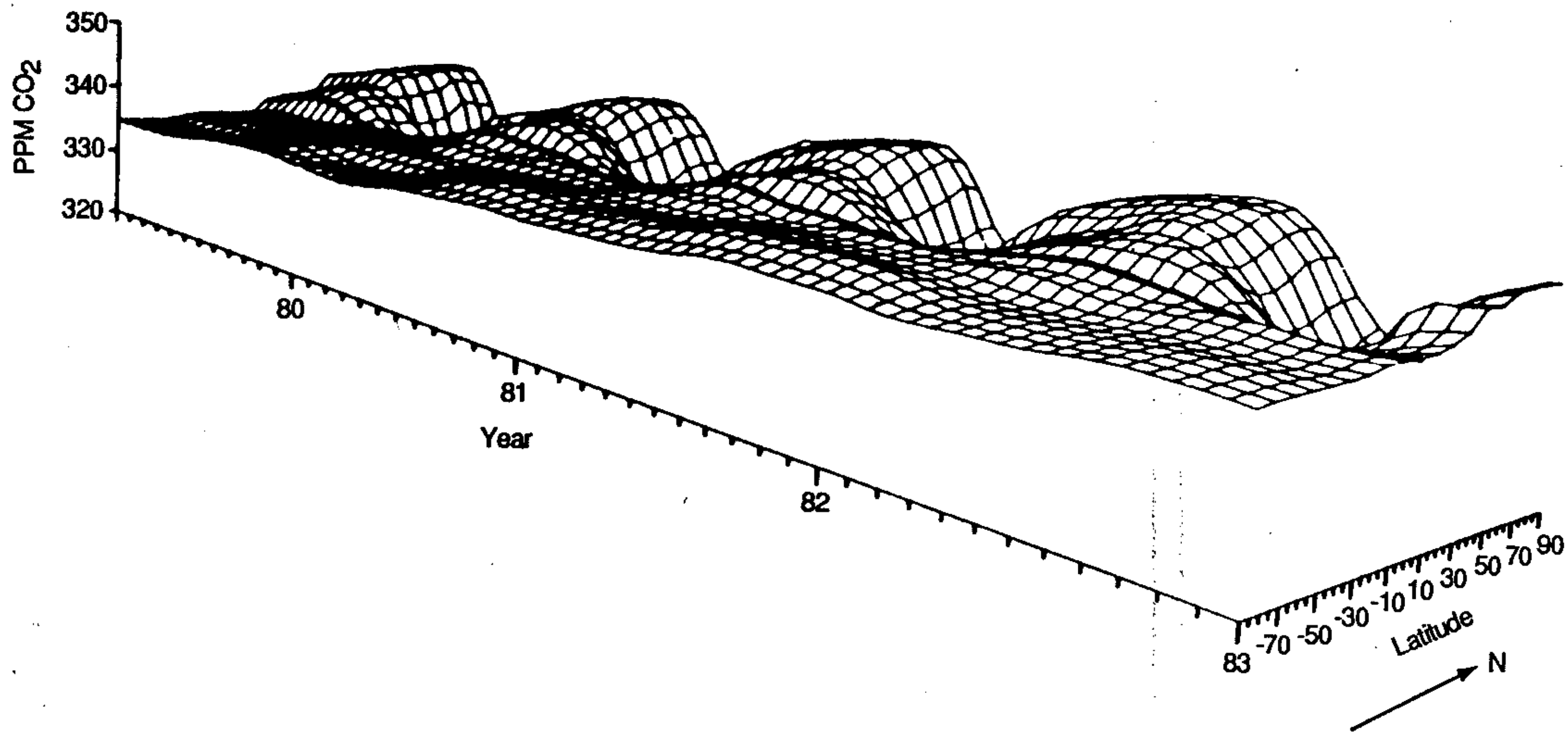

Figure 3.3. Atmospheric Carbon Dioxide Levels as a Function of Latitude

3.6 THE GREENHOUSE MECHANISM

What happens when we load the atmosphere with these greenhouse gases? Well, the basic picture is very simple. You can think of these gases as a kind of blanket that lets most of the sunlight penetrate to the land surface or the oceans where it is absorbed. After it is absorbed, the sunlight is converted into heat, or what we call "infrared radiation." Although the sunlight can penetrate to the earth's surface, the infrared radiation from the surface is trapped by the greenhouse gases. Some of this trapped heat energy is then reradiated back to the earth's surface, and some is reradiated upward. Thus, the greenhouse gases act like a blanket with a one-way filter, letting more sunlight through than heat energy out, and that is how they warm the surface of the planet.

3.7 SCENARIOS OF FUTURE CLIMATE CHANGE

Next, I am going to show you some pictures that describe the effect of increasing the amount of carbon dioxide in the atmosphere. When I say increasing the amount of carbon dioxide, I want you to think of that not necessarily as all extra carbon dioxide. Some of it might be carbon dioxide, but some of it might be other greenhouse gases (e.g., nitrous oxide, methane, or chlorofluorocarbons).

Figure 3.4 shows the climate consequences of several different scenarios for the emission of carbon dioxide to the atmosphere. The curve labeled A is for slow exponential growth, or business-as-usual; the curve labeled B is for limited emissions, or linear growth; and the curve labeled C is for terminated

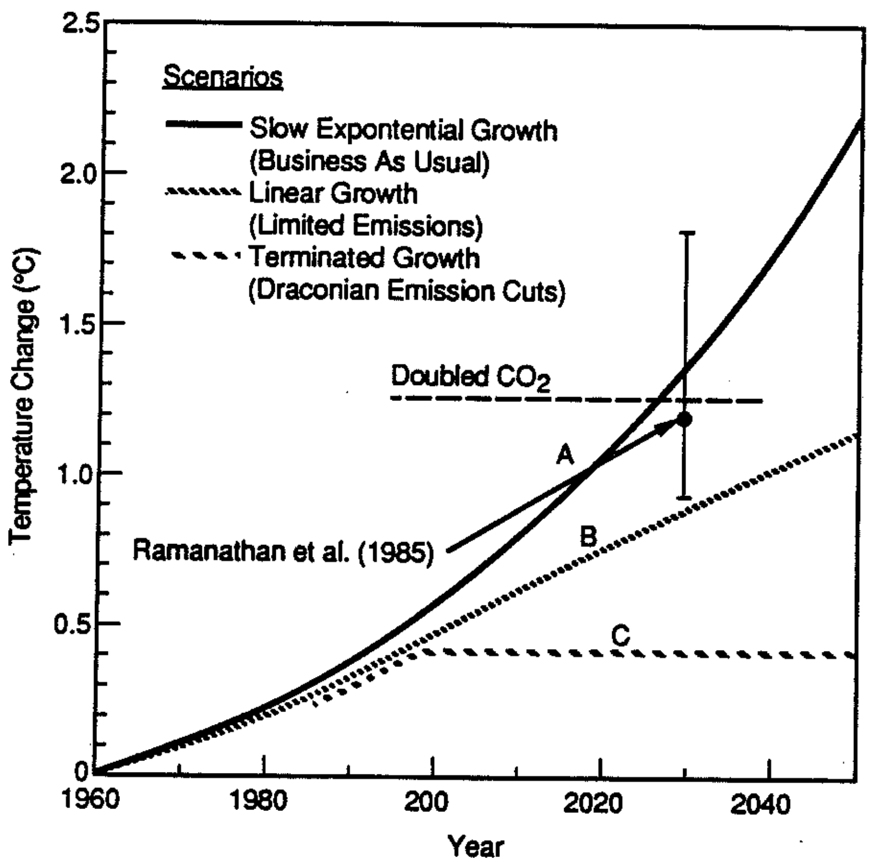

Figure 3.4. Climate Consequences of Different Carbon Dioxide Emission Scenarios

growth, or Draconian emission cuts. I am not going to try to define in detail these scenarios because they are rather complicated in the way they are formulated, but I should say that the limited emissions scenario requires a cessation of growth in fossil fuel use as well as a cessation of deforestation. The linear growth scenario requires a major commitment to energy conservation so that emissions are limited, but not as severe as in the terminated growth emissions scenario.

The temperature increase shown in Figure 3.4 is not the whole story. It includes none of the climate feedbacks that amplify this direct effect of carbon dioxide. Here is an example of a feedback mechanism. As heat is reradiated to the surface and the surface is warmed, the water on the earth's surface is also heated. When you heat water, more of the water evaporates. So, under these circumstances, more water vapor will be present in the atmosphere. More water vapor in the atmosphere further heats the planet because water vapor, like carbon dioxide, nitrous oxide, and methane, is also a greenhouse gas. In fact, in our atmosphere, most of the *natural* greenhouse effect comes from the water vapor in the air. So, as the water vapor increases in concentration, there is what we call a positive feedback effect. The warming from the carbon dioxide leads to warming brought on by the additional water vapor in the atmosphere, which in turn increases the thickness of the blanket, so the effect amplifies. That amplification is not shown in Figure 3.4, which just shows what climatologists call "direct greenhouse forcing."

Figure 3.5 shows the effects of the identified and well-understood feedback processes, including the water vapor mechanism, under the same scenarios. I have not placed uncertainty limits on these graphs, but if I did, they would be large. The different groups who run the climate models get different answers. One group will differ with another somewhat, and when you vary some of the assumptions in the models, you get different answers. Roughly speaking, you can assign ±1.5°C of uncertainty to the points on the steeper curves. Despite the claims of some skeptics, there is virtually no way in which an increase in greenhouse gases could cool the planet.

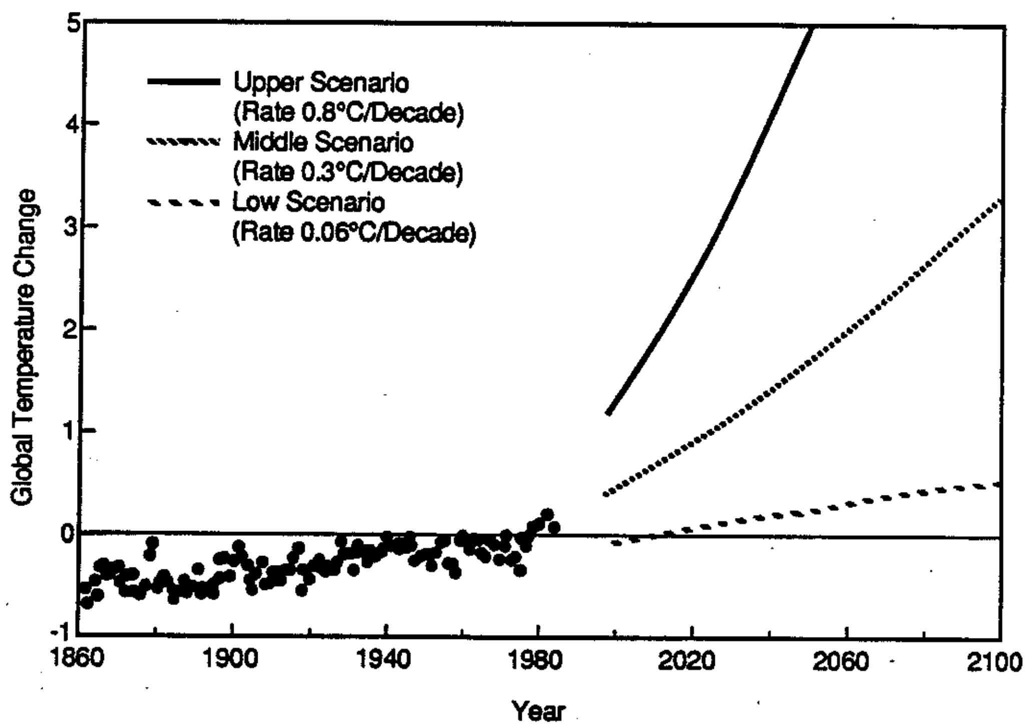

Figure 3.5. Effects of Identified and Well-Understood Feedback Processes

The results are expressed as a warming rate in units of degrees centigrade per decade. The reason I am presenting the predictions as degrees per decade is that in many ways that is a more useful way to think about the consequences of climate change than to think about it as absolute temperature increase by some fixed future date. It would be useful to know how much warmer it will be in the year 2050, but what will really affect more of our day-to-day lives and the way we respond to climate change and the way crops, sea levels, and natural ecosystems respond to climate change is the rate of warming. When you think about it in terms of degrees per decade, you can begin to think about it in terms of the speed with which the society may have to respond to the changes in climate.

3.8 VERIFYING CLIMATE MODELS

Next, I want to mention very briefly some of the reasons why we ought to have confidence in the models and the model results that I have presented. There are three planets that we understand very well in our solar system. We understand Earth pretty well, and we know quite a bit about Mars and Venus but we do not understand them completely. One of the things that we know about Venus is that it has an enormous amount of carbon dioxide in its atmosphere--hundreds of times more than in the Earth's atmosphere. Mars on the other hand has less carbon dioxide than earth. We also know our own surface temperature very well, and we know the surface temperatures of Mars and Venus from satellite probes. When we apply the same climate models to predict the surface temperature for those planets, we get very good agreement with the surface temperature data. The models predict that Venus should be as hot as it is and that Mars should be as cool as it is. That is not great evidence, but at least it gives us some assurance that the models are not completely off target. If the model can work for such extreme conditions, you should have a little more confidence that it reasonably predicts conditions on Earth.

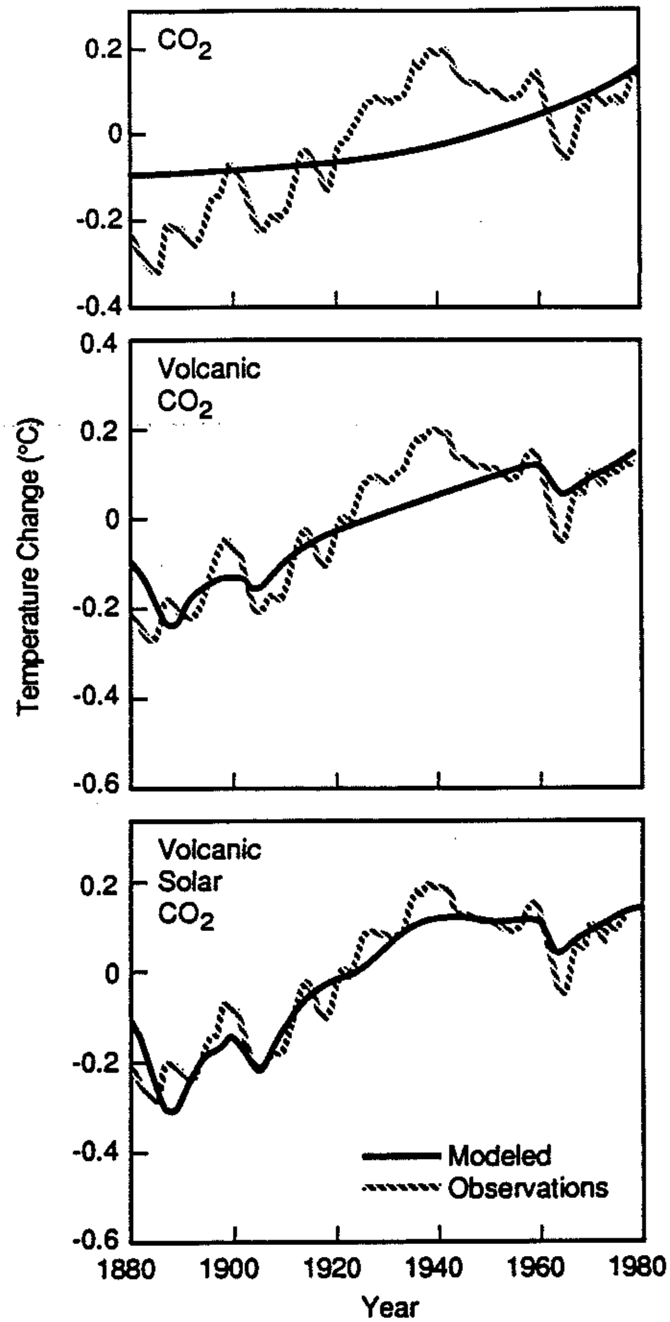

Figure 3.6. Global Temperature Data, Measured and Predicted

Another reason for some confidence in our models is shown in Figure 3.6. This information is very controversial and these graphs are several years out-of-date, but the basic idea is captured here. The record for the last 100 years of globally-averaged temperature data is shown by the dashed line. Even though there are ups and downs, there is an overall upward trend. What would the increasing amount of carbon dioxide in the atmosphere do to the temperature of the planet over the last 100 years? The prediction of the models is shown here as the solid line. The prediction does not simulate the last 100 years very well. However, as the figure shows, if you include volcanic eruptions (which alter our climate by emitting material that blocks sunlight and causes cooling and changes in solar output from sunspot activity), you get a reasonable picture of what has happened over the last 100 years.

This is the optimistic picture. There are meteorologists who have attacked this argument. They quibble with the database, for example, arguing that some of the data come from weather stations that are located near cities. The urban heat island effect spreads out over time to influence data collected at a weather station that might be located outside a city or town. Therefore, part of what you are seeing is not global warming but the spread of the city.

However, if you exclude the urban and suburban stations and look the rural and oceanic stations, I believe you still see an increasing trend. That argument is not over; people are still debating the issue. I don't want to give you the misleading impression that we are confident that we know what we are talking about, but that there is some evidence that we can have confidence in our models.

There is another argument that is sometimes made for confidence in the models. If you examine paleoclimatic history--back over hundreds of thousands of years--you find that during periods when it was very warm, the carbon dioxide levels were very high. And during periods when it was cold, the carbon dioxide levels in the atmosphere were very low. "Aha," you say, "that makes us think that the models are right." The models predict that when the carbon dioxide levels are high, the temperatures should be high, and when the carbon dioxide levels are low, it should be cold. But the catch in all of this is that we do not understand the cause-and-effect relationships. The carbon dioxide fluctuations over the past hundreds of thousands of years could very likely have been a consequence, not a cause, of the temperature fluctuations.

Indeed, the paleoclimate data suggest that there may be an interesting mechanism by which warming triggers an increase in the carbon dioxide levels. Whatever the mechanism is, it needs to be understood because there may be such a positive feedback mechanism at work in today's climate system.

One such positive feedback process is the warming of soil, which speeds up bacterial decomposition of organic carbon present in the soil. In the soils of our planet, there are 3 to 4 times more carbon than in the atmosphere. This large pool of carbon in the soil, if released through warming, could add tremendously to the amount of carbon in the atmosphere. One of my former students, Dan Lashof, evaluated that feedback process in his doctoral dissertation. He showed that it is indeed a positive feedback effect, but that it is not going to lead to a further doubling of carbon dioxide. It is not a large correction in our understanding, but it is in the direction of adding carbon dioxide. There may be other mechanisms that we are not fully aware of that may cause the carbon dioxide levels to increase above and beyond the levels produced by the burning of fossil fuels and by deforestation. If so, they nearly certainly involve changes in ocean circulation.

3.9 THE EFFECTS OF CLIMATE CHANGE: TEMPERATURE INCREASES

Next, I want to mention briefly why we are worried about a warming of a few degrees. After all, if tomorrow were 2° colder or 2° warmer than it is today, you probably would not even know unless you read the weather report in the newspaper. We can feel when the arctic front comes through and the temperature drops 20° overnight, but how can you tell that you are being subjected to a couple of degrees warming? Figure 3.7 shows most of the last million years of earth's temperature record. Obviously we did not have thermometers in place all that time, but these are reconstructions of temperature from numerous sources such as the pollen record and ice cores. The ice cores tell us about how much carbon dioxide was in the air, and they also tell us something about temperature. There are isotopes--rare forms of elements--that are locked into the ice; the amounts of those isotopes, such as heavy oxygen, depend on temperature because they diffuse at rates that differ from the rates for the common forms of the elements. Therefore, temperature can be deduced from the chemical composition of ice.

From Figure 3.7, we see a sequence of fluctuations, of glacial advance and glacial retreat. According to these data, it is warmer now than it has been

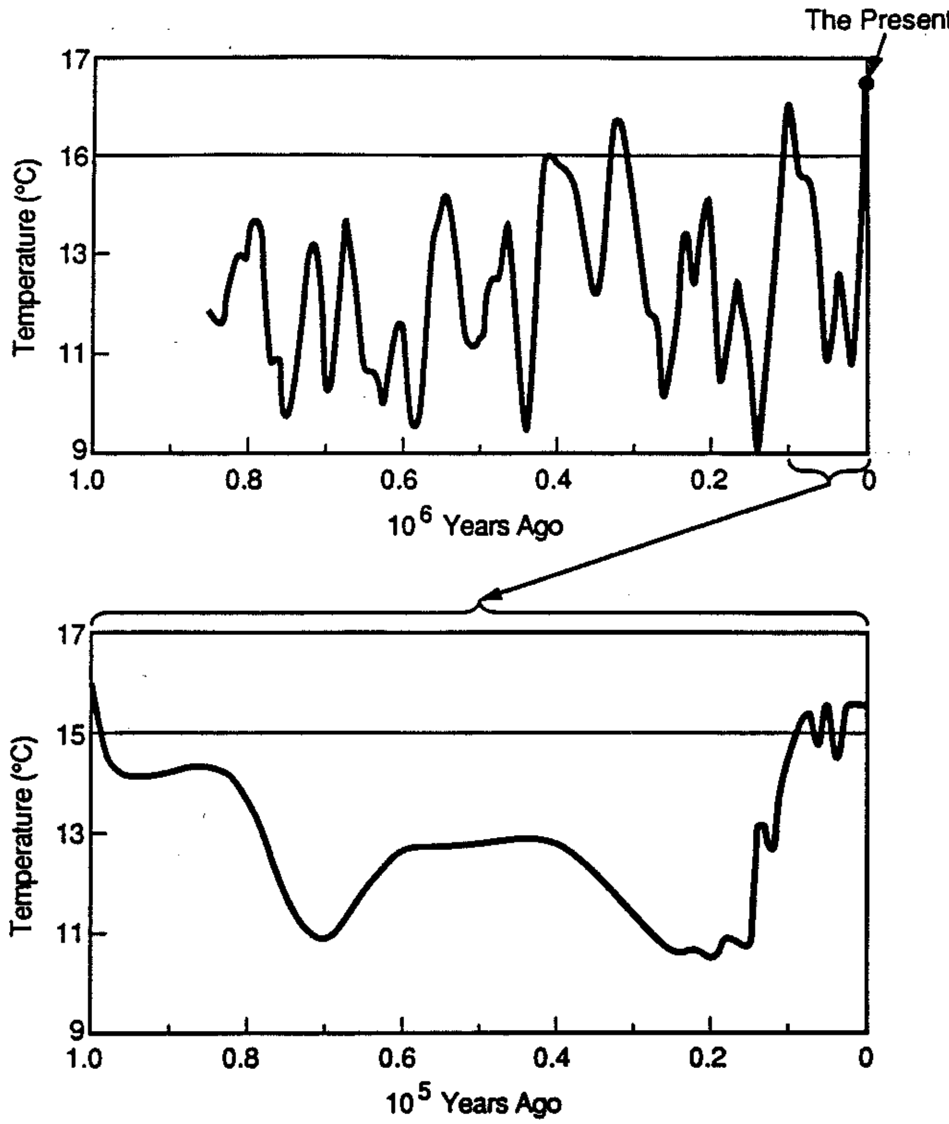

Figure 3.7. Global Temperature Fluctuations

at any time in the last million years. In fact, you have to go back about 65 million years ago to the Cretaceous Tertiary boundary to find a period when it was *significantly* warmer than it is today. In the age of dinosaurs, the earth was in a very warm period. You really have to go back a long way to find significantly higher temperatures--temperatures that are 3° to 4° warmer than they are today--yet that are the magnitude of the predicted warming over the next 50 to 100 years. So in terms of our climate history, we are doing something very dramatic to our climate.

Will this happen? It depends how committed we are to energy conservation, to stopping deforestation, and to reforestation. It is not something that is deterministic. We can influence the odds tremendously with our actions. The important point I want to make is that we are talking about a warming that is very large. It will make us warmer--much warmer than we have been in perhaps millions of years of climate history--and we will be doing this in 100 years.

Think about the changes that have occurred on the planet since last Ice Age, shown in Figure 3.7 as the cool period 10 to 20 thousand years ago. Think about how species distributions changed. Think about how some species became extinct and others became dominant because of the altered climate. That was the result of a magnitude of warming similar to that which the greenhouse gas buildup will cause, but spread over thousands of years instead of 50 to 100 years. So we are talking about major stresses on the planet. They are both large in magnitude and rapid in time. That is why we are concerned.

3.10 EFFECTS OF CLIMATE CHANGE: PRECIPITATION

We are not just interested in temperature increases. If you are a farmer, you care about soil moisture. We have a much poorer idea of the affects of the greenhouse problem on precipitation rates than we do of temperature increases. It is much harder to model precipitation. Precipitation predictions involve knowing a lot more about clouds and storm formation than we know. So we have to make our best guesses about where it will rain more and where it will rain less. If you look at the different models that are used to study the greenhouse effect you will find that they agree pretty well on temperature increases, but they disagree on precipitation changes. Some models say there will be more rain in a particular place and other models say there will be less. Most models seem to say it is going to get drier in the breadbasket of North America, and it will be drier in some major areas in the Soviet Union and southern and eastern Europe. It undoubtedly will be wetter in certain other parts of the world. But we are a lot less confident about those predictions than we are about the temperature prediction. This issue is vitally important because soil moisture has such a major impact on agricultural productivity.

I was in the Soviet Union about 4 years ago talking with scientists interested in climate change. Some climatologists there were arguing that perhaps in the Soviet Union there would be a benefit from climate warming. After all, they do not have major cities located along the coastlines like we do. If sea level rises by 0.5 meter over the next 50 years, which is quite possible due to the thermal expansion of the oceans and the melting of ice, it could cause havoc in our coastal cities. It could of course cause even more havoc to places like Bangladesh, where vast numbers of people live and farm very close to sea level, but it might cause less harm in the Soviet Union. The Soviets might find themselves with warm water year-round ports for their submarines if the sea temperatures increase. There are wild speculations that to us seem like science fiction but that are being discussed over there. They are arguing that perhaps global warming is not such a bad thing, and perhaps it should be encouraged. It would put them in a better relative situation at least. Maybe they would suffer, but they would suffer less than some other countries.

Fortunately, as I have corresponded with people in the Soviet Union, I have found that in the last year or two they have become much more serious and concerned about the problem, and the optimists who think some benefits come from it are not in great numbers now and have very little influence. I think that is partly because Soviet President Mikhail Gorbechev has been very concerned about the problem and is setting a tone that is very positive and constructive. The consequences of a reduction in soil moisture are surely part of the reason for their concern.

3.11 CLIMATE/BIOSPHERE INTERACTIONS

The greenhouse effect can assert a direct influence on the biosphere, including ourselves, our crops, and also the natural ecosystems. The effects of climate change on biota are mediated by effects that go on in the geosphere as shown in Figure 3.8. A warming of the soil can change the atmosphere and, therefore, can amplify the greenhouse effect. By changing soil conditions you also will change the nutrient status of the soil, and that may affect crop productivity. There are numerous relationships that link the greenhouse effect with other aspects of the geosphere, and those in turn can all affect the biota. In addition, we are not just doing things that affect the climate these days. For example, we are also loading the atmosphere with pollutants that form acids that are, in turn, damaging lakes and possibly forests. We are emitting substances that affect the ozone layer, and we are cutting vast forested areas in the tropics. And all of those other anthropogenic stresses interact with changes that come about from the greenhouse gases. Generally, when you look at those interactions, you find that they are synergistic

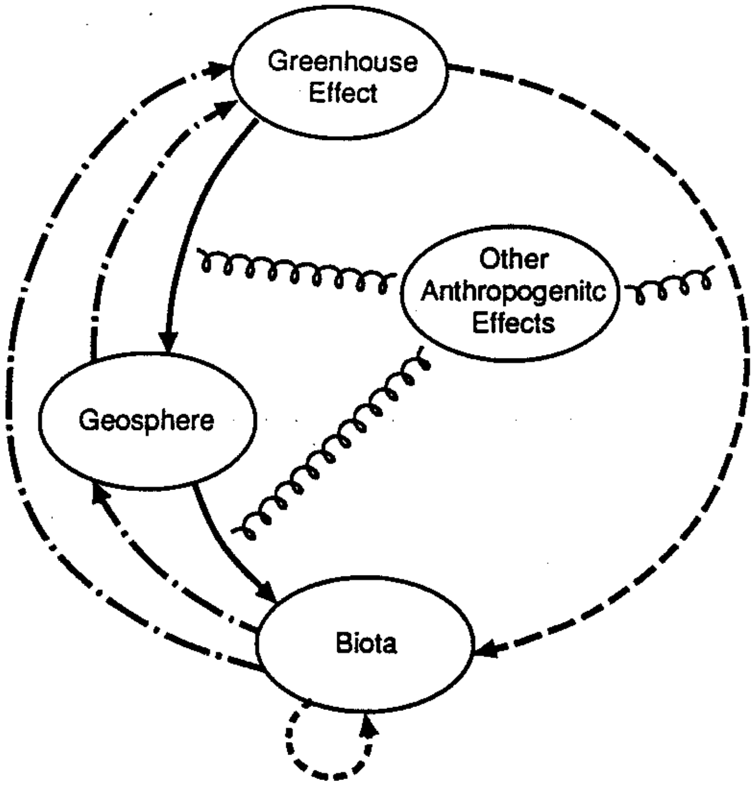

Figure 3.8. Links Among the Greenhouse Effect, the Geosphere, and the Biota

in a bad sense: the stresses caused by climate change add positively to the effects of acid rain or deforestation to make the combined stresses much worse than the sum of the parts.

Within that simple picture of planetary feedback loops shown in Figure 3.8, there are numerous internal processes that need to be considered, and only a few of them have been studied in any detail. We have trace gases produced from the burning of fossil fuels and the use of nitrate for fertilizer. These kinds of activities increase the concentrations of greenhouse gases in the atmosphere and, thus, contribute to climate alteration. Climate alterations affect ocean circulation and ocean biology, which in turn can be a sink or source for trace gases. The climate change also affects vegetation, which in turn changes the reflecting characteristics of the earth's surface. A planet that is very dark tends to absorb sunlight. A planet that is shining (for example, if it is covered with ice) will reflect sunlight. Therefore, the surface characteristics of the planet affect the climate. Climate change can do things to affect the surface of the planet. It can melt the ice so more sunlight can be absorbed, thus amplifying the warming effect. Climate change can turn land that was once covered with forests into deserts, which may influence regional and global climate. Climate change can also affect the distribution and productivity of ecosystems and the distribution of species in ecosystems. The effects of climate changes on the feedback processes are enormously complex. These effects have only begun to be studied, and we are undoubtedly in for numerous surprises as we continue to study this problem.

Consider the fogs off of the coast of California. In California and parts of Oregon, the summer fog is our summer air conditioning system. San Francisco is a cool city in summer because of its famous summer fogs. Fog also provides moisture for the chaparral and the redwood forests. These summer fogs result from ocean upwelling. The deep ocean waters are cool and as winds blow across the ocean surface, they generate an upwelling of cold water to the ocean surface through a mechanism called Ekman pumping. That cold water cools the atmosphere above it, and then as the moisture-laden sea breezes come in, the water condenses on that cool air and fog is produced. The fog ultimately results from the winds that produce the upwelling. In a "greenhouse" world, where carbon dioxide levels are doubled, the pattern of winds would be expected to change. As the winds change, the degree of coastal upwelling would be affected. This is an example of an indirect effect that is only now beginning to be understood. When the rates of upwelling of ocean water off the coast change, sea surface temperatures change, and that process can affect fog and coastal temperature. Productivity and marine biodiversity are affected because the upwelling water is rich in nutrients, and if the rate of upwelling changes, the supply of nutrients to the fisheries off the coast would be decreased (see Figure 3.9). One of my graduate students is now working with some biologists to integrate this whole picture and try to make some estimates of what the effects will be. The idea is to use the output from the climate models to tell us how the winds will change and then to include those changed wind conditions into a model of upwelling. We hope that this approach will give us a picture of how the upwelling changes, and will allow us to at least qualitatively evaluate these effects.

You will notice one further relationship here. The fog in summer affects forest fires. We have a problem with fire in California in the summer because of the dryness. However, it would be much drier if we did not have the fog. Forest fires are influenced not just by fog but also by other conditions, such as temperatures and rainfall. Several of us are looking at the problem of how fire intensity will change if we have a doubling of carbon dioxide, which changes precipitation, temperatures, humidity, and wind (and, therefore, upwelling and fog).

3.12 PROBLEMS OF TIMING AND GEOGRAPHICAL DETAIL

One of the problems in trying to do these analyses is that we are lacking some very important information about the details of the climate change. If we look at a model's rainfall prediction for a particular month, the model may indicate that we are going to get 15% more rain. Depending on the assumptions used in the model, the 15% more rain

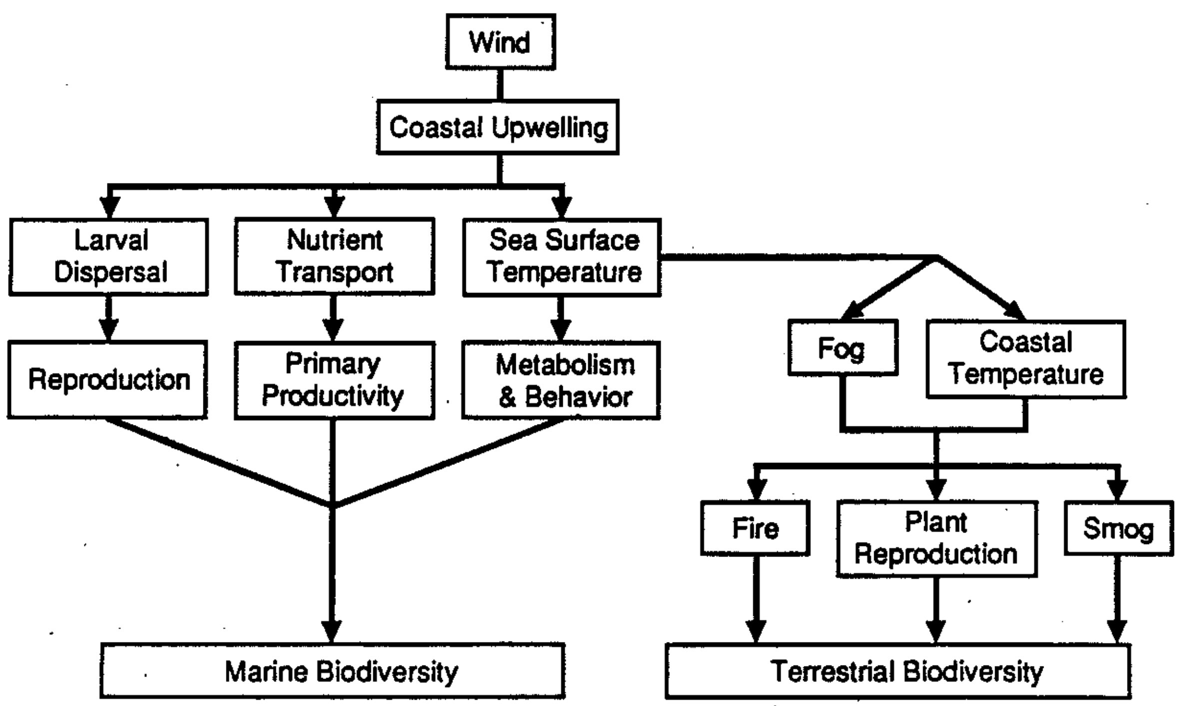

Figure 3.9. Mechanisms That Contribute to Marine and Terrestrial Biodiversity

could be distributed proportionately over the month or it could all be distributed over a period during the middle of the month (Figure 3.10). There is a world of difference between these two assumptions when you are concerned about forest fires. In the first case, you have a long dry period just as long as you did before the extra rain fell, and that is the period in which a fire has a chance of starting and possibly turning into a major forest fire. In contrast, a 15% increase in rainfall distributed in the middle of what would have been a dry period will greatly reduce the frequency or intensity of forest fire. The climate models we are using today are just not capable of telling us with any confidence which of those two possibilities is most likely. The number of possibilities is endless, of course. It does not have to be one of these two, but the point I want to make is that the models need to be improved with respect to their temporal resolution and also their spatial resolution.

The models now predict what goes on in squares that are roughly a few hundred miles on a side. In California, one of the squares can include the deserts and the mountains, or the coasts and the agricultural croplands. And we know things vary a lot within those squares. It would be wonderful to have models that can deal with smaller geographic regions and finer time scales, but days or weeks rather

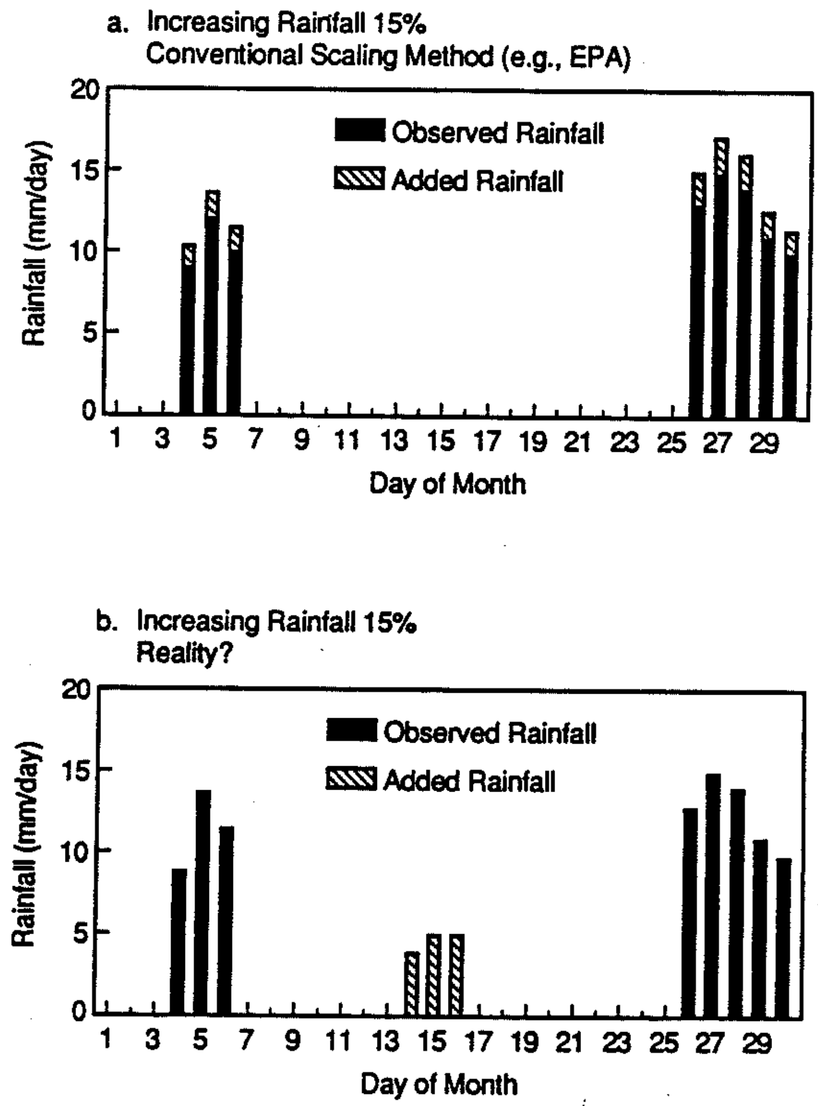

Figure 3.10. Effects of Increasing Rainfall by 15%

than months, and tell us the results with accuracy. The models can give us climate predictions on a roughly hourly basis now, but there is no basis for confidence in such predictions. Unfortunately, it is extremely difficult to improve the situation, because we do not have computers that are large and fast enough to handle the data requirements those kinds of fine-tuned predictions would require. So, at the moment, we are limited to predictions that do not make it possible to evaluate the ecological effects with anything like the certainty that we would like. We are all hopeful that in the future the climate predictions will become more fine-tuned, and then we will be able to obtain better estimates of ecological consequences.

3.13 QUESTIONS AND ANSWERS

Question: I have a question concerning the forests becoming deserts. The absence of vegetation and declining cloud cover would seem to point to a increasing warming. Is that what you are suggesting?

Answer: Well, there are competing effects. If you take a dark area like a forested area that absorbs sunlight, and you replace it with something that is shinier, which has a higher albedo, as the climatologists call it, you reflect more sunlight back into space. You absorb less on the surface. So the direct warming effect of the sunlight will be less. On the other hand, you would interfere with the hydrological cycle. You would not be transpiring water to the extent that you were. You would be changing winds and storm patterns. You would be doing a lot of things that also can influence the weather. When you put all of that together, it is very difficult with existing models to say for sure that it will cause a warming or a cooling. It is easier to say it will cause a drying than it is to say what the temperature effect will be. We are pretty confident things dry out when you cut down the forests. It is a lot harder to say what the effect will be on global or regional temperature.

Question: This is just a point of clarification. When you said that there were 2° to 5° warming by the next century, were you referring to 11 years hence or 111 years hence?

Answer: The middle of the twenty-first century.

Question: Is that Fahrenheit or centigrade?

Answer: That is centigrade, sir. Everything I said about temperatures was centigrade.

Question: You mentioned that the source of carbon dioxide was from, or a lot of it was from, the burning of fossil fuels. What are the sources of the burning of fossil fuels and what percentage of the carbon dioxide comes from the various sources?

Answer: You could see that on Figure 3.1, which showed gaseous, liquid, and solid fuels. It showed liquid and solid fuels contributing about equally. This is worldwide, not just the United States.

Question: I meant more specific sources such as coal-fired power plants, automobiles, industrial plants?

Answer: All of the major ways we use energy contribute significantly. That is, if you divide energy consumption into electric production, transportation, industry, and home-heating, you find that all four of them are sufficiently large that it pays to try to do all four of those things more efficiently. No one of them is such a small contributor that you can just forget about it and say let's not bother trying to improve the way we do that activity. If we insulate our homes so that we use less fuel for space heating, we will make a significant difference. If we can improve the efficiency of our cars, we will make a big difference. If we can cut down on energy consumption by using more efficient refrigerators and the like, we will make a big difference. And if we can improve industrial processes, we will make a big difference.

Question: When you look at your million-year and hundred-thousand-year cycles, there are obviously a number of cold cycles apparently driven by something other than carbon dioxide. How do we know that the carbon dioxide warming effect will not be overlaid on a cold cycle?

Answer: That is a very good question. First of all, a clarification. Those cycles that occurred over hundreds of thousands of years are probably not driven by carbon dioxide. Carbon dioxide does change as the temperatures change, but it changes in response to the temperature change. Now what does cause those fluctuations? To the best of our present knowledge, the major cause is due to changes in the amount of sunlight reaching the earth, and its distribution over the course of the seasons. And the reason that it changes is that the earth's orbit about the sun is not uniform from millennium to millennium. The earth has an elliptic orbit about the sun. And the shape of that ellipse changes with a 100,000-year cycle, roughly. Now, there is a 100,000-year cycle in those data. It was a little hard to see because it was not a perfect sine wave, but if you analyzed it you would see that there is a cycle. And we think that cycle is due to the cycle of the earth's orbital geometry, which is also about 100,000 years. Now there are also 20,000-year and 40,000-year cycles in the amount of sunlight reaching the earth because of subtleties in the position of our orbit. The tilt of the earth's axis about the plane in which the earth circulates around the sun. The earth circulates with a tipped axis and its polar axis moves like a top. It precesses, and that kind of influence can change the climate tremendously because it alters how much sunlight is received at what time of year. Those effects then can amplify other processes that are internal to the earth, feedback effects of the sort that I mentioned. And those are the things that we think caused the major patterns that you saw in that historical look at climate change. What is unique now, is that something completely different namely the anthropogenic buildup of carbon dioxide in the air is acting in a sense to overwhelm those things. But the other important point is that those cycles occur with time constants of 20,000 years or 40,000 years or 100,000 years. And there is no way, unless we are completely wrong about the causes of those cycles and their relative regularity, that all of a sudden in the next 100 years they are going to conspire to save us. This is because we know where we are in those orbital cycles, and the cycles are slow. They do not change anything very much in a 100-year time period. They only cause change in 20,000-year time periods. So it is highly unlikely that something we don't understand about the climate that caused past change is going to reverse the big experiment we are doing on the atmosphere.

4.0 THE GREENHOUSE EFFECT: THEORY OR FACT

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In my remarks this morning, I will attempt to convey what we know about the greenhouse problem and what we do not know about the problem.

Last June 23, a colleague of mine, Jim Hansen, whose name has been mentioned several times already, testified on the greenhouse effect before the U.S. Senate Committee on Energy and Natural Resources. I think his written testimony began our increased awareness of the greenhouse effect and also may have given us an erroneous perception about our understanding of the greenhouse effect. In his testimony, Jim wrote:

> "Thus, we can state with about 99% confidence that current temperatures represent a real warming trend rather than a chance fluctuation of the 30-year period."

On the back side of the written page of his testimony he wrote:

> "Global warming has reached the level such that we can ascribe with a high degree of confidence a cause and effect relationship between the greenhouse effect and the observed warming."

I think in the minds of many people the juxtaposition of these two statements of verbal testimony has given the impression that we have detected the greenhouse effect with 99% confidence. If you tell Jim Hansen that is what he said, he will disagree with you. In fact, it is not what he said, but it certainly gives you the connotation. Around the world, we had a drought, crops baked, temperatures soared, farms folded, barges stuck in a dried-up Mississippi River, food prices soared, the economy shuddered, and people looked to the sky for some kind of sign. All of that was supposed to be a preview of the impending greenhouse effect. The drought was real. The cause of the drought, although sometimes attributed to the greenhouse effect, was not really understood.

The perception of people about the greenhouse effect has been raised so high that I was intrigued when I saw Oregon Ballot Measure 7 having to do with the Oregon Scenic Waterways System. In this ballot measure, there was an opposition argument that brought up the greenhouse effect in two places. First, the greenhouse effect was described as already here and impacting our weather patterns, so whoever wrote up that argument is a believer. He is actually right. The greenhouse effect is here, but that is not what we are all talking about here. We are talking about an increase in the greenhouse effect as I will describe later on. And secondly, he went on to say, ". . . this initiative will leave us no practical alternative but to generate energy by burning fossil fuels, which pollute our atmosphere and contribute to the worsening greenhouse effect, or by using nuclear fuels which may pollute both the surface of the planet as well as the atmosphere." So here is, in fact, the existence of the greenhouse effect being used by someone who is in opposition to the Oregon Scenic Waterways Bill, which in fact was passed despite his opposition. Not all scientists concur in the kind of statement that Jim Hansen has made. And in fact, I think most scientists do not agree with that kind of statement for reasons of which I will elaborate as I continue.

A former scientist at the Lawrence Livermore Laboratory recently wrote an article entitled "The Greenhouse Effect, Science-Fiction," and he went on to describe his reasons for not believing what has been said about the greenhouse effect.

On June 23, the *New York Times* came out with an editorial by Nicholas Wade, who talked to me the day before Jim Hansen's testimony was made. But the transcript was released and Nicholas Wade wrote a very intelligent article about it, saying in part, ". . . I believe the greenhouse effect is real enough . . . ," and he concluded that, ". . . several measures to slow the greenhouse warming are worth taking for reasons other than the greenhouse as well as for the greenhouse. . . . Cut the production of freons. . . ." Those are the chlorofluorocarbons that destroy the ozone layer in the stratosphere. Nobody is in favor of ozone destruction. "Protect tropical forests." Deforestation increases greenhouse gases. "Encourage energy conservation." Almost nobody is against that, except that it is something you want someone else to do, not yourself! And lastly, ". . . develop cheaper, safer nuclear power." I say something about that towards the end of my talk.

So I titled my talk "The Greenhouse Effect: Theory or Fact," and let us examine what we know about this and what we do not know about it.

Here is an outline of my presentation. Although I generally forget the outlines, they help me be organized. I will give you an introduction concerning the carbon dioxide issue, actually the greenhouse issue focusing on carbon dioxide. Next, I will talk about methods that can be used and are being used to project future climate change. I will talk about two such methods. First, the approach of my Soviet colleagues, which is called the climate analog, uses the past as potential models for the future. The second, the mathematical modeling approach, is used in the rest of the world. I will describe to you what a mathematical model is, and what its many limitations are. Then I will show you results from such models for the change in the equilibrium climate of the earth due to a doubling of the carbon dioxide concentration. That is a hypothetical kind of situation because, naturally, the carbon dioxide concentration does not instantly double. It is a question we have been addressing for the last 15 years to see if this issue is worthy of further study. The last topic will be the nonequilibrium climate change. That is the actual climate change that is going on, or may not be going on, on the earth.

4.1 CARBON DIOXIDE IN THE EARTH'S ATMOSPHERE

Let us begin with the one thing we know for sure, the concentration of carbon dioxide in the earth's atmosphere as measured at Mauna Loa in Hawaii. These measurements were started in 1958 through the actions of Dave Keeling, who is at the Scripps Institute of Oceanography. Although today everyone agrees that it was worthwhile to make these observations, Dave Keeling had a heck of a battle to get funds to set up the carbon dioxide monitoring station of Mauna Loa for the International Geophysical Year starting in 1957. If he had not persisted, we would not have this information.

Let us begin with the concentration as an annual average, so it removes the seasonal cycle due to the respiring of forests in the Northern Hemisphere is removed. The Mauna Loa data show what we all know, that the carbon dioxide concentration in the earth's atmosphere has increased from about 315 ppm in 1958 to about 350 ppm, which was the latest measurement. That is an increase of about 35 ppm over 315 ppm, or roughly 11%. Therefore, we see about a 10% to 15% increase during the period of record, which is about 30 to 31 years.

Having seen this, it was compelling to attempt to identify what the carbon dioxide concentration was before 1958, before we had these measurements. The carbon dioxide concentration has increased as a function of time from the middle of the eighteenth century until the present. Well, we can get an estimate of carbon dioxide concentrations in the air from analysis of ice cores from Antarctica. Every year, snow falls on Antarctica, and year-after-year the falling snow compacts the snow underneath and turns it into ice. As that happens, the air in the atmosphere is trapped in the ice and so by taking a core from the ice, extracting the air from the core, we can get an estimate of what the composition of the earth's atmosphere was in the past. The compaction the snow into ice captures air over about a 30- or 40-year period so we get an average picture from each slice of the carbon dioxide concentrations over a time period. At the dawn of the industrial age in the middle of the eighteenth century, the concentration was about 280 ppm. By the middle of the nineteenth century, it was perhaps 290 ppm, an increase of only 10 ppm in a 100-year period. From the middle of the nineteenth century to the time when Dave Keeling's measurements began, we saw an increase from 290 to 315 ppm. That is a four-fold increase when compared with the preceding century. From 1958 to the present (a period of over 30 years), the carbon dioxide concentration has increased by an amount equal to the increase experienced in the previous 100 years, indicating that the rate of increase of carbon dioxide in the earth's atmosphere is accelerating.

The causes for the increase in carbon dioxide are predominantly the burning of fossil fuels. From 1860 to 1960, the rate of increase was about 4.2% per year, year after year, except for three time periods: World War I, World War II, and the Great Depression. In times of economic duress, our use of fossil fuels decreases.

The same kind of results are seen from 1950 to the middle of the 1980s. The rate of increase was again about 4.2% per year. That is, every year, we used about 4.2% more fossil fuel than before. This increase continued until we reached 1973, when we had the oil embargo and the rate of increase dropped to about 2.2% per year.

The rate of increase of carbon dioxide is something that we ourselves are causing. It is not a natural change in the carbon dioxide concentration; it is something that we are doing to the earth's atmosphere by our use of these fossil fuels. John Harte showed in his presentation the world's carbon dioxide production in billions of tons of carbon. The total is what I want you to focus on. The total leveled off in 1973, around the time of the oil embargo, continued to increase the maximum rate before prices increased in 1979, and then leveled off again. It has now begun to increase again. We now have more or less returned to where we were before the oil embargo in terms of putting fossil fuels into the atmosphere, despite our concern about the greenhouse effect.

Roughly speaking, when the cost of fossil fuels goes up, the level of emissions goes down. When the cost goes down, there is some lag in the response, but in fact, the emissions have increased again. This results in concern about our use of fossil fuels, but I want to point out one salient fact. We as Americans tend to overlook that we are not the only people on the planet. In 1950, the United States contributed 42%, just a little less than half, of all the fossil fuel and carbon dioxide emissions to the atmosphere. We bear a pretty large responsibility. It will make it difficult for us to go to other people in the developing world and say, "... don't do as we did, do as we say you ought to do, for the good of global humanity." Presently, our contribution has dropped to about 21%. The Soviet Union contributed about 12% in 1950, and now their contribution is about the same as ours. It is interesting to look at the per capita carbon contribution into the atmosphere by country. Our per capita contribution has increased, and interestingly enough, the Soviet Union's contribution has increased enormously. What is most interesting, though, is the emergence of China, which is now contributing 10% of the world's emissions. China has an abundance of coal, and I don't think they are going to be swayed very heavily by our arguments to not use it to improve their economic position. Japan's contribution is also increasing. But the contributions from other places in the world are relatively small in terms of percentage contributed. When you look, however, at China and India, their per capita use of fossil fuels is very, very small. But the number of people in these countries is enormous. So if in the next century, they (not unreasonably) would like to have the same per capita energy consumption that we presently enjoy, you can get a real appreciation of the potential difficulty of solving the greenhouse problem. It is not a problem for the developed nations of the world exclusively. It is a problem for all the nations of the world.

4.2 FORECASTS OF EMISSIONS

Having seen the past increase in carbon dioxide indicated by the Mauna Loa record, it is only natural to attempt to make projections into the future. Of course, there are uncertainties inherent in taking that approach, because our use of fossil fuels depends on the economic situation. If there are economic downturns because of depressions or recessions (hopefully not wars), then perhaps the amount of fossil fuels we use will go down. The sample projections that I am going to discuss are uncertain, and they have been made in a way that takes into account the uncertainty. From such projections, we can get an idea about the possibilities for increasing carbon dioxide in the next century. There are socioeconomic and ecological uncertainties, and there are physical-system uncertainties about how much carbon dioxide is taken up, for example, by the ocean. Tens of thousands of projections are made. You pick uncertain quantities from probabilistic distributions for each of the uncertain quantities, and then you make your projection. You do this tens of thousands of times, and then you can rank the resulting evolutions that you get in terms of percentiles.

The 50 percentile means that half of the projections were below that level and half were above that level. The 95 percentile means 95% of the projections were below that level. The 5 percentile, means 5% of the projections were below that level. The concentration of carbon dioxide at sometime in the next century will be equal to twice the concentration of carbon dioxide estimated to have existed in 1850. The time of carbon dioxide doubling for the 95 percentile projection occurs, say, in the year 2020, the median (50th percentile) in 2050, and the 5 percentile in 2100. So, we have every reason to believe that sometime in the next century the carbon dioxide concentration will be twice what it was in the middle of the last century.

Carbon dioxide is a greenhouse gas, but it is not the only greenhouse gas. It is a natural greenhouse gas, but we are also emitting some unnatural greenhouse gases into the earth's atmosphere namely the chlorofluorocarbons, Freon 11 and Freon 12. Measurements were also made at the Oregon Graduate Center from 1976 to about 1986, and the Freon concentrations increased. Measurements were also made of nitrous oxide, methane, carbon tetrachloride, and methyl chloride. The data showed that these greenhouse gases are increasing, and this hastens the doubling time, making it more likely that sometime in the next century, the concentrations of carbon dioxide and the other greenhouse gases will effectively equal twice what they did in the middle of the last century.

4.3 EFFECTS OF GREENHOUSE GASES IN THE ATMOSPHERE

What would be the effect of doubling the carbon dioxide concentration in the earth's atmosphere? The earth's atmosphere is mainly composed of two gases, nitrogen at 78% and oxygen at 21%. Together, these two gases make up 99% of the earth's atmosphere. Water vapor, which is very variable in space and time, makes up about 0.2%, and carbon dioxide, at 300 to 350 ppm by volume, makes up only 0.03%. To make all that information understandable, I will put it in more vivid terms. If we take the atmosphere from the surface of the earth to outer space, as we go upwards the pressure decreases, the density decreases, and the temperature decreases. We can bring a column of air all the way down to the surface of the earth and keep it at the same temperature and pressure that we have here now. If we do that for the whole atmosphere, the air column would be 6 miles long. Of that 6 miles, carbon dioxide would make up only 10 feet. So it is a minor constituent. What would happen if the carbon dioxide concentration doubled and the column became 6 miles and 10 feet long, with the carbon dioxide level then being 20 feet? How can that possibly have any impact on the climate of the earth? Well, we can make calculations of what the temperature at the surface of the earth would be if the earth had no atmosphere. The earth would then absorb radiation from the sun, and it would warm up. As the temperature increases, the earth would emit radiation back to space. The earth would warm up until the amount of radiation emitted to space equals that absorbed from the sun. At that point, the system would be in equilibrium, and the temperature would be 60°F colder than the actual temperature at the surface of the earth.

Suppose that we put an atmosphere with 99% nitrogen and oxygen on the planet. If we do the calculation again, the calculated temperature for the surface of the planet is again 60°F colder than it actually is. Why then is the surface of the planet as warm as it is? The reason it is 60°F warmer has to do with the presence of the greenhouse gases, which are primarily water vapor, carbon dioxide, and ozone. All three of these gases combined make up less than 0.25% of the earth's atmosphere in terms of volume. In terms of the thermal regime of the earth, the primary gases in the atmosphere are minor. Well, you could legitimately ask, why do these gases raise the temperature by 60°F? Why are they greenhouse gases, and why the other gases are not? I can give you an answer to that, but the answer requires a review of physics. Oxygen and nitrogen molecules each have two atoms. These molecules are symmetric. Water vapor has three atoms per molecule. A molecule of carbon dioxide has three atoms and so does a molecule of ozone. These molecules have three or more atoms and are not symmetric (at least not always), and for that reason they can absorb the radiation emitted by the surface of the earth towards outer space and thereby block reradiation. This is the blanket effect John Harte discussed. Since the blanket effect prevents reradiation of the energy to outer space, the temperature of the planet's surface increases until a new equilibrium state is achieved.

4.4 ESTIMATING THE EFFECTS OF CHANGING CONCENTRATIONS OF GREENHOUSE GASES ON TEMPERATURE

We have every reason to believe that increasing carbon dioxide levels in the atmosphere will change the climate of the earth. The question is by how much, how fast, and where will the climate change? How can we address this issue? How can we study what the future climate of the earth is likely to be? Can we go into the laboratory like a physicist and a chemist and construct a miniature earth--a rotating planet having land and ocean and mountains and valleys with an atmosphere and a sun and perform controlled experiments. Unfortunately, we can not do that because the system is just too complicated. There is no way that we can replicate it in the laboratory to perform that kind of classical study. How else can we study it? One way, the way my Soviet colleagues have done, is to use the past as a model for the future. This approach is called the climate analog approach. Those who use this approach hope that the past climate is an analog for future climate. Let me share with you some of the results of my Soviet colleagues. I will also explain why they use the climate analog approach rather than the mathematical modeling approach we use.

Michael Budyko is in Leningrad, and he uses this climate analog technique. He is, in fact, the head of the Soviet delegation that is in charge of writing a report on future potential climate. I am writing the chapter on the theoretical modeling calculations of potential future climate change. I talked with him in August in Leningrad, and he explained his approach.

The Soviets estimate that the sensitivity of the climate system is 3°C (or about 6°F) for a doubling of carbon dioxide levels in the atmosphere. This number came from some modeling results, but they also used evidence of past climates of the earth to develop their estimate. They projected the carbon dioxide concentration, not unlike what I just showed you, for the years 2000, 2025, and 2050. They assumed some lag in the response of the climate system relative to the increase in greenhouse gases for reasons that I will explain later in this talk. With these three pieces of evidence, the temperature change for the three years 2000, 2025, and 2050 were projected to be 1.3°C, 2.4°C, and 3 to 4°C respectively.

From these temperature changes relative to 1900, the Soviet researchers reviewed the climate record of the earth and picked past times when the climates were as much warmer than 1900, as the values projected for the future. For example, for the year 2000 (i.e., for the 1.3°C warming), they picked a time that is called the climatic optimum, which existed 5,000 or 6,000 years before the present. During this time, the Sahara Desert was a savannah, and we think that civilization dawned in that region because of the favorable climate.

For the year 2025, the projected warming is 2.4°C. We are presently in an interglacial period, a warm period as opposed to a glacial period that is an Ice Age, the maximum of which was 18,000 years ago. The last interglacial period was 125,000 years ago. The available evidence indicates that the last 2.4°C warming occurred about 125,000 years ago. Projecting out to the year 2050 for a 3 to 4°C warming, we have to go back to 3 to 4 million years ago. So to see past warming periods that are comparable with those that were projected you have to go 120,000 years in the past and then 3 to 4 million years further back to find when it was that warm on the earth under normal conditions.

From tree rings, pollen, and other natural recorders of environmental conditions, Soviet and U.S. researchers have information that may describe past climates. Using this information, researchers have also made estimates about precipitation during those three times compared with today. For the change in precipitation projected for the year 2000 relative to 1900, you have to go back 5,000 to 6,000 years. During that period, over large regions of land that is now the Soviet Union, the so-called paleoclimate analog indicates an increase in precipitation. In North America, there was a decrease in the amount of precipitation.

Similar projections have been made for other time periods. These projections indicate that in the year 2025 the precipitation in the Soviet Union will continue to increase, while for North America there will be a continued decrease in precipitation. Finally, in the year 2050, precipitation in the Soviet Union will continue to be above what it was in 1900, while for North America, the precipitation trend will reverse, increase, and then become favorable. Based on the information from these projections, Michael Budyko concluded that we should burn *more* fossil fuel in the future to reduce the period of water stress for the United States, to benefit the Soviet Union, and return to a paradisiacal condition where the earth is warmer and more humid, and people could simply live off the earth's bounty. I do not agree with that conclusion.

4.5 CLIMATE MODELS

There is another way of studying potential, future climate--develop a model of the earth's climate system. A model of climate is first and foremost nothing more than a statement of the physical laws of nature, such as conservation of energy and mass, Newton's second law of motion, etc. These are things I think everybody should have heard about in their education. It is just a statement of what we believe are the laws of nature as deduced from observations by human beings.

To be able to make use of these laws we have to manipulate them, which requires that we express them mathematically as certain types of equations. These equations govern the distribution of the wind field, the temperature, the surface pressure, the amount of water in the atmosphere, for example, continuously in space and in time. By this I mean, regardless of how close two points are on the earth's surface, you can calculate the temperature, the pressure, and the precipitation. This approach can result in equations, which are the mathematical statements of the physical laws, that are so complicated that we do not know how to solve them analytically. What do I mean by an analytical solution? To illustrate, if I ask you to calculate the square root of 4.3, somewhere in our education we presumably learned the rules for making this calculation. However, there are no such rules for solving the equations that are the mathematical statements of the physical laws. Therefore, to make progress, we need to alter these equations from being continuous in time and continuous in space to being discrete. For example, we subdivide the atmosphere vertically into layers and horizontally into grid boxes. We construct, thereby, a system of three-dimensional boxes--cubes if you like--at the centers of which we calculate the temperature, the precipitation, the water vapor, the cloud amounts, the snow on the ground, etc., everywhere over the surface of the earth. We have to make this kind of a sacrifice in order to solve the equations and make any progress.

Now in doing this, of course, there are certain costs. First of all, the resolution of the model cannot be infinite. The resolution of the grid boxes for my model, which has the highest horizontal resolution of the five models that have been used worldwide to study the greenhouse effect, is about 300 to 1,000 miles on a side. You can see that such horizontal resolution gives only one or two points in an entire state for states like Washington and Oregon, and even California. This is very unsatisfactory, because for the impacts of the change in climate, you want information on a much finer horizontal scale than that. So why not simply increase the resolution of the model to a point that would give us results on the scale that we want? Suppose I increase the resolution by a factor of 10 from 300 miles down to 30 miles. That change would certainly give us a lot more information. However, if I did, I would require a computer not 10 times faster than the Cray XMP that I use now (which is one of the world's fastest computers), not 100 times faster, but in fact, a computer 1,000 times faster would be required. If I increased the north-south resolution by a factor of 10 and by a factor of 10 east to west, there would be 100 times more grid boxes than existed before. We solve these problems by integrating forward in discrete time steps ranging from 10 minutes to 60 minutes. If I decreased the size of my grid boxes, I also would have to decrease the time step by a factor of 10. That is the third factor of 10. The effects multiply. If we increased the scale by a factor of 10, we would need a computer 1,000 times faster than the computer we have been using, which is the fastest computer available.

In fact, this is the very reason the Soviets cannot do the kind of calculations that we have been doing. Their computers are much slower than our computers. And to illustrate that, I estimated how much time it would take to run a Soviet climate model on their computers. I estimated that the calculation on the Soviet computer would have taken 4 CPU (central processor unit) years. No computer stays up 100% of the time, so if you figure that the machine would stay up maybe one-third of the time and they might have to share it with others, they could take 12 elapsed years to make that calculation. Well, that's almost slower than the climate systems themselves.

To solve this problem, we are going to bring the Soviet model to the United States and run it on our computer. On the super computer that I use, it will take about 160 hours, just to give you some idea.

The Soviets have relied on the analog technique primarily because their computers cannot handle the calculations required by the mathematical modeling approach.

We have to include the oceans in these models. In the past we have included very simplified models of the ocean, again for computational economy. In the beginning, we used what was called a "swamp ocean." This concept considered the ocean to be like perpetually wet land. It would never dry out, but it has no heat capacity, so it does not require any additional computing time for the climate system to reach equilibrium (that is, additional time in computing to get to the equilibrium solution). We used these models to calculate so-called annual average climate change. We used annual average sunlight, so there was sunshine everywhere on the earth all the time, day or night, and there were no seasons. These assumptions are very unrealistic, but the results we got from those models suggested that the greenhouse effect was sufficiently important to study that we went to another kind of model of the ocean. This model contained an upper-mixed layer where the temperatures are uniform with depth down to about 60 meters. With this kind of model, you can put in the annual cycle of sunshine and calculate the change in seasonal climate due to increases in the greenhouse gases. Finally, we now can construct models of the ocean that include the dynamics of the ocean, all the way down to the ocean bottom. We then may control calculations. In effect, the computer becomes a laboratory in which we now can make controlled calculations.

To perform these calculations, we start the model at some initial time with some concentration of carbon dioxide, usually between 300 and 330 ppm by volume, and then we integrate forward in time in steps as small as 10 minutes to 1 hour. We have the solution not on monthly time scales, but with much finer resolution to address all sorts of questions. The model finally reaches some sort of initial statistical equilibrium with the concentration of carbon dioxide, the distribution of land and ocean, and the amount of sunlight. We then double the carbon dioxide concentration in the model, perform the controlled experiment, integrate forward in time until the new statistical equilibrium is achieved, and then take the difference between the two. That is the carbon dioxide induced climate change. For the swamp ocean, this takes a simulation of about a year. We did this 15 years ago when our computers were not as fast as they are now. The results of those calculations showed that the problem was significant, so we continued to improve on how we treated the ocean in the model. We next used the so-called well-mixed layer. This kind of model takes about 20 simulated years to get to equilibrium, and then you simulate 10 years beyond that to get a good measure of the statistics of the climate, like the average and the variability about the average.

If we use a dynamic ocean model, which we in fact need to do to go all the way to the bottom of the ocean, it takes a simulation of 1,000 years to reach equilibrium. Simulations like that are the ones I told you were going to take 4 years on a Soviet computer and a week on a U.S. computer. It is for that reason that no one ever made the calculation. We are very much limited by our computers.

What do the models tell us? Everything that you have read in the past 7 months or so and before about the greenhouse effect, is really predicated on the results from these models. There are only five models in the world that have been used--four in the United States, one of which is mine, and one in the United Kingdom.

We can take a look at equilibrium climate change by posing the question, "How much will the temperature increase as a result of increased carbon dioxide, say, hypothetically for doubling of the preindustrial concentration?" To accomplish this we make one calculation with the carbon dioxide concentration at 330 ppm by volume--that is 10 feet out of 6 miles. Then we make another calculation where we double that concentration, so it becomes 20 feet out of 6 miles instead of 10 feet, and see what the temperature change for the planet will be.

4.6 CLIMATE MODEL RESULTS: TEMPERATURE

Five different models have made calculations of the temperature effect of doubled carbon dioxide--one by the Goddard Institute of Space Studies in New York City; one by the National Center for Atmospheric Research in Boulder, Colorado; one by the National Oceanic and Atmospheric Administration (NOAA) Laboratory at Princeton University; one by the United Kingdom Meteorological Office (UKMO) group; and mine. The results all show a warming of the planetary atmosphere that ranges from about 2.8°C to 5.2°C. Of course, global average warming is what we anticipated, and here we have quantitative estimates; although, they do not all give the same number for reasons that we believe we understand. The precipitation for the planet increases and, in fact, the size of the increase in precipitation is tied to the size of the increase in temperature. The larger the temperature increase, the larger the percentage increase in precipitation.

If we compare the warming simulated by the five models, the warmer the model simulates the present climate, the smaller the sensitivity. The colder the simulation of the present climate, the larger the sensitivity. This is because in a colder climate more ice is present in the ocean. When you double the existing carbon dioxide, the sea ice begins to melt. The very bright sea ice is replaced by the darker, underlying ocean that absorbs more sunshine and enhances the warming. Thus, more sea ice melts, and a positive feedback loop is established.

Another feeling that one would get from comparing these models is that if all the models more accurately simulated the observed climate (and the observed is not well known), they would all simulate the same sensitivity. That would mean that the models are giving roughly the same results, and that would be encouraging. But I am glad that the models do not all agree, because if they all agreed we would undoubtedly take their results as being true. And since they do not, we cannot. And even if they did agree, it does not mean that the results would be correct. You can ask yourself, "How can you verify a model sensitivity for a climate yet to occur?" Unfortunately, that is a very fundamentally difficult question to answer.

In three of the models, we looked at the change in the temperatures both as a function of latitude from the South Pole to the North Pole and as a function of altitude. The temperatures are averaged with respect to longitude. Start at some longitude, average all around the earth at that latitude and altitude and you get the average temperature change. Three of the five models show cooling in the stratosphere, which increases with increasing altitude, and warming everywhere in the troposphere, which also increases with increasing altitude in the tropical latitudes. At the surfaces there is a warming that increases towards the winter pole, which in the Northern Hemisphere is December, January, and February.

Qualitatively, there appears to be a lot of agreement among the models; however, quantitatively there are differences. Qualitatively, all of the models show geographically similar patterns, minimum warming in the tropical latitudes and warming increasing towards both poles. Of course, they are going to disagree quantitatively, because the global averages disagree. We can discount that by correlating the patterns of the temperature changes among the models. If you do that, you find a fair amount of agreement.

4.7 CLIMATE MODEL RESULTS: WATER SUPPLY AND ENERGY DEMAND

Next, we consider the predicted changes in soil moisture. I want to show you some impacts, and I want to discuss the nonequilibrium situations. Three of the five models show a continental-scale drying in the Northern-Hemisphere summer. It is this drying that has raised a lot of concern about the potential impacts of greenhouse gases and induced climate change on agriculture, water availability, and water quality.

The U.S. Congress charged the EPA to conduct a study of the potential effects of changes in the climate on the United States. This has been prepared in a report to the Congress that has not been released yet. The EPA took three of the five models, the Goddard Institute for Space Study Model, the Geophysical Fluid Dynamics Laboratory Model, and my model, and they looked at the temperatures and precipitation, and the potential impacts on water resources, wetlands, fisheries, agriculture, air quality, and electricity.

Let's talk about the results of the EPA study on the impacts on electricity, since that is of the most interest here. The study projects an increase in power demand for the southern-tier states, while the northern-tier states show a projected decrease. The increase in the South occurs because of an increased need for air conditioning, and the decrease in the northern tier occurs because of the decrease in the need for space heating. Overall, the change is positive for the United States--estimated to be a 4 to 6% increase. The cost in 1986 dollars is from $33 to $73 billion. However, there are some things that this study did not include. They did not consider the impacts on demand for natural gas and oil for home heating, which will likely decrease. Also, they did not estimate changes in electricity supplies due to sources such as hydropower. They also looked at the change in the peak demand. The change for the United States is projected to be an increase of 200 to 400 gigawatts (a billion watts is a gigawatt). That is an increase of 10% to 23% and the cost is $175 to $325 billion. To meet this demand, they say, however, would increase the U.S. carbon dioxide emissions substantially, particularly if we meet the demand by using coal-fired power plants, which as I know is a sensitive issue here.

4.8 NONEQUILIBRIUM CLIMATE AND POLICY

I want to say some things about the nonequilibrium climate and get on my soapbox a little bit. How much warming has there been since 1850, and how does it compare with that expected from the carbon dioxide increase since then? Well, what we have been talking about so far is the equilibrium climate change--that hypothetical doubling that has not occurred and that will not occur instantaneously.

Several organizations have reconstructed the record of the average temperature of the earth, including a group from Leningrad, one from GISS, and one from the Climatic Research Unit, University of East Anglia in Norwich, England. All three records show reasonably good agreement. So much so that it is difficult to distinguish among the data sets if all three are plotted on a graph. There are differences, however. If you were to look at just the end points, you would see that there has been a warming of the planet of maybe 0.5° to 0.6°C over the last 100-year time period. You would see that the warming was not monotonic year after year. You would see that there was a warming from 1880 to about 1940. In fact, in 1936 scientists were making statements not unlike those heard last summer. The year 1936 was the warmest year on record. They knew that carbon dioxide was increasing in the atmosphere, although they did not have the Mauna Loa data. Based on that information and knowledge, they predicted continued future warming. However, the system was a little more complex than they understood--it still is--and the warming ceased. In fact they observed no warming or a slight decrease in temperature until about the middle of the 1970s, after which the warming resumed.

I want to discuss the time scale for climate change. If we calculate the carbon dioxide induced warming from 1850 to 1980 based on the sensitivity of the models we have used to predict a 4°C temperature increase, we get a warming of about 1.1°C. However, the records indicate that we have experienced a temperature increase only about half as large as that. What does that mean? It could mean is that our climate models are two times more sensitive than nature. Another possibility, however, and the one that actually occurs, is that there is a delay in the response of the climate's system to an increase in carbon dioxide or any other greenhouse gas. That delay is caused by the ocean. The water in the ocean can move horizontally and vertically. Moving vertically, it can take the heat from its the surface down into its interior, and the heat that is left is smaller than what would otherwise be on a planet without an ocean.

Using very simple models, researchers have estimated that time delay in observed warming due to a given increase in carbon dioxide would range from 10 to 100 years. If the delay was 10 years, the climate's system always would be virtually in equilibrium with the carbon dioxide concentration. For example, if the time delay is 10 years, we should have seen a warming of 1.1°C from temperatures observed 10 years ago. We have seen only half of that temperature increase, so the conclusion could be that our models are too sensitive. If the delay is 100 years, it would mean that the system was in equilibrium with the carbon dioxide concentration approximately 100 years ago, and the warming would be considerably less. That assumption is a little oversimplified, but it is useful. To find a better answer, we used a more sophisticated climate model at Oregon State University. We made a calculation, and we found out that the warming delay time is on the order of 50 to 60 years. That means that the climate in some vague sense is responding to the carbon dioxide and other greenhouse gas concentrations of 50 or 60 years ago. Now that has very strong implications, not only for detecting climate change but for the amount of time we have to be able to do something about it. I will try to explain this point.

Consider the warming from 1850 to 1980 as a function of the sensitivity of the climate system for a carbon dioxide doubling. If we take 3.5°C as that sensitivity and if we do not have oceans on the earth, we should have seen a warming of 1.1°C. With oceans on the earth that take heat down into their interior, the warming should be only about half of 1.1°C. From this calculation, we can say that the sensitivity of our models is not inconsistent with the record of climate change we have seen over the last 100 or 130 years. However, the Catch-22 of the role of the ocean climate change is, if we do not increase the carbon dioxide concentration any more in the earth's atmosphere, temperatures will continue to increase until an equilibrium is reached. The indication that we have not reached that equilibrium yet has strong implications for the time that we have available to be able to do something about this.

The information I have just discussed could be plotted on a graph showing the contribution of the greenhouse gases to the temperature change of the earth from 1880 to the present, depending on how much delay time you allow the system to have. If you have zero delay time (a planet without an ocean), the temperature instantaneously is in equilibrium with the overhead greenhouse gases. In that case, the warming that we should have seen due to all the greenhouse gases, is about 1.3°C. The rate of change of the slope of our graph should increase in about 1960 due to the addition of the other greenhouse gases at that time. Before that time, there was only carbon dioxide.

If you allow 60 years delay time as my calculations suggest, then you can explain the observed warming from 1880 to the present, roughly. That warming is about 0.5° to 0.6° for the planet. However, the observational record is much more complex than that. If the observed warming represents the greenhouse effect, then what caused the warming from 1880 to 1940, before there had been much increase in greenhouse gases? If the observed warming represents the greenhouse effect, then what caused the cessation in warming in from 1940 to 1970 and then the resumption? We do not know the answers to those questions.

That gives us a reason to be cautious about what we can say about the future climate for the earth. We believe that there are other factors influencing the climate changes, such as changes in the sun and changes in volcanic activity, but most confoundingly we believe that the system has natural variability.

Any February, like this February, is different from the climate of any other February. We can only appreciate that there is natural variability from year to year, from decade to decade, and maybe from century to century. It is against this natural variability that we have to try and see the signal that is given by the greenhouse gases. When that signal is small and there is some change in the record, you do not know whether you are seeing the greenhouse signal or whether you are seeing the natural variability. It is only when the signal gets to be so large that it is unlike anything that we have seen before that you can have increased confidence that you have detected the greenhouse gas induced climate change.

However, because of this role of the ocean in delaying the response, by the time you have that kind of assurance, your ability to do something about it is strongly diminished. There is what I call the detection-mitigation dilemma. You can think of the dilemma graphically. Time is on the horizontal axis, percent is on the vertical axis. The confidence that we have detected the climate change and that it is attributable to the greenhouse gases increases as we go through time. And unlike the connotation given by Jim Hansen's statement--that is, 99% confident--I believe that scientific understanding of this problem is such that our confidence that we have detected the greenhouse gas-induced climate change is much smaller. I would start pretty close to zero, and, as time goes on, I would show an increasing confidence that we have detected a greenhouse-driven climate change.

There is, however, another curve on our graph that would show our effectiveness in mitigating the change in climate or adapting to climatic change. The sooner we take appropriate action, the more effective we would be, so effectiveness diminishes with time, relative to what we could do now. Sometime in the next century, our children or their children, will be able to look out here and say, "Well, we detected that the climate has changed on the earth. We know that it is due to the greenhouse gases, but there is very little if anything we can do about it. Why did not those folks at the end of the 20th Century do something about it when they had the opportunity?" But we living in the present, we are looking to the future, and I am afraid that it does not look like that. We see only the first tiny portion of the curve. If we knew what the whole curve looked like, we would be doing something about it. Unfortunately, we are uncertain, so we have to make decisions in the face of uncertainty. Of course, decision making is always made in the face of uncertainty.

I constructed a diagram after I had given a talk to the Academy of Sciences in Amsterdam, and a staff member of the Minister of Environment asked me, after a long talk, what should we do about this? And I described two actions. One of these actions was an accelerated study on the physical climate system, which is what I do, because in the world there are only about 10 people working on this issue and we are busy, as you can tell by the fact that I am here. We could use more resources if we are going to decrease the uncertainty of our understanding of this very complex system in a time period short of the actual systems performing this kind of an experiment. Secondarily, and what my questioner in Amsterdam was really interested in, was what can we do about the problem? I then thought of the dilemma that I described previously. What I believe we need to do is to make projections across a wide spectrum of human endeavors of the impact of climate change.

Presently, when we make plans for future hydropower, coal power, agricultural productivity, etc., we assume (implicitly if not explicitly) that the climate of the future will be like the climate of the past in almost all regards. We use not only the averages, but the statistics other than the average as well. If there is any one lesson that we can take from our climate model studies to date, it is that the constant climate assumption is not correct. The climate in the future will be different from that of the climate of the past. How is it going to be different? We have some indication that it will be warmer and wetter in some regions and drier in other regions. However, the models we are using now have limitations.

In view of these limitations, we need to begin to make assessments. In fact, I recently received a report from New York State, where they are beginning to do some assessments. The assessments could take the following form. For example, suppose we do nothing, and we are right about the future. Then there is going to be a cost involved. On the other hand, suppose we do something, or everything, and if we are wrong about the future, then we are going to pay a price as well. However, we can make analyses like that for different alternative strategies for the future and assess the cost-benefit ratio for each of those different strategies. I think that is what we should begin to do now as I and the nine others in the world who are working on this problem continue to try and refine our understanding. The bottom line here is, many climatologists expect that the projected changes in the greenhouse effect will eventually prove true. Of course, we are reluctant to issue alarmist warnings prematurely and such caution is justified. But there is an ample case for taking initial preventative measures when the cost of such measures is so low and before the discomforts and costs resulting from climate change are so abrupt.

5.0 EFFECT OF GLOBAL WARMING ON PACIFIC NORTHWEST HYDROLOGY

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This presentation is perhaps a bit mistitled, because I am going to try to draw some inferences about Pacific Northwest hydrology from some work that was done in California.

First, I want to say just a word or two about what hydrology is and what hydrologists do. Hydrology is basically concerned with three phenomena, evapotranspiration, precipitation, and runoff, and hydrologists get paid to describe these phenomena in terms of space and time.

5.1 INTRODUCTION: HYDROLOGY AND WATER RESOURCES PLANNING

Hydrologists are also concerned with water resource systems analysis and runoff management, which is a closely related but more applied field. Typically, we have an historical record (time series) of stream flows, and a reservoir or reservoirs that we want to manage for various purposes (for example, power generation, water supply, flood control, recreation). We can then account for the changes in storage in the reservoir over time within some obvious extreme constraints (e.g., the reservoir cannot be completely emptied, and it cannot be overfilled).

One of our major concerns is the reliability with which reservoir releases can be made for a given purpose. One measure of reliability is the probability that we are going to meet our resource management goal. From a hydrological perspective, some of Michael Schlesinger's comments regarding uncertainty bear on how we estimate stream flow. Usually, operation of a reservoir or reservoirs using historical stream flows is simulated. That is the method that is almost always used for determining reservoir reliability; we just count up the number of times that we would have met our target, divide that number by the total length of record, and we have an estimate of reservoir reliability. To enhance reliability, we might consider building new reservoirs, or we might want to think about how we operate existing reservoirs. All of this planning is based on the idea of a statistically stationary, historical time-series of flow; that is, there is an implicit assumption that, hydrologically, the past is a good indicator of what will happen in the future. Obviously, stationarity is one of the things that is being called into question when we talk about the greenhouse effect.

I also want to discuss some of the factors that might influence the reliability of a water resource system. Clearly, the annual mean (average) stream flow will be important, but stream-flow variability is also very important. In addition, the mean stream flow in each season, and the seasonal variability, can be important. Other statistics having to do with the persistence of stream flows (e.g., whether high flows tend to follow high flows, and low flows tend to follow low flows) are also important. If we have multiple reservoir systems (as we certainly do in the Pacific Northwest), the stream flow structure between different sites is important to us as well.

Again, everything at present is tied to this idea of stationarity and the analysis of past stream flow records. In planning studies, we usually do not worry about what caused an event (for instance, an extreme flood or drought). We recognize that an event happened and then do the analysis. This is a standard engineering analysis approach. One problem we have in doing this kind of analysis is that we need relatively lengthy sequences. Giving us 5 years of stream flow and asking us to say how reliable a reservoir system is--whether or not it is going to perform adequately in droughts and so on--does not really help very much. We typically need data for about 50 to 100 years. In the Pacific Northwest, the standard period that is used for reservoir analysis is from 1928 through 1968. The period starts in 1928 because many gauges were installed in that year. For the Columbia River at The Dalles, there is much more lengthy period of record (about 100 years).

That sets the stage for the kind of issues that hydrologists deal with. The particular results I am going to present here provide a little different way of looking at things if future stream flows were to change. They are based on a study that was done in California as part of the EPA reports to Congress that were previously mentioned. We wanted to develop an understanding of both the hydrology and the water resource system operations. We can draw some inferences about the Pacific Northwest because the hydrology of California is not unlike the hydrology of the Columbia Basin. Snow accumulation in the winter and spring snow melt runoff dominates the hydrological cycle in both areas.

5.2 APPROACH

The general approach that was taken in the California study used multiple steps to simulate flow from meteorological data rather than simply examining historical stream flow. Historical flow, since it is keyed to the historical climate is not very useful to us. We have models that use meteorological inputs, typically temperature and precipitation, to predict runoff. These runoff prediction models are essentially quasiphysical process models. In some sense, they might be considered analogous to the general circulation models (GCMs) used to predict climate change. Hydrologists will argue about which model is the best. We used the National Weather Service Forecast System for four headwater catchments in California. Figure 5.1 shows the location of these catchments, which were titled "index catchments."

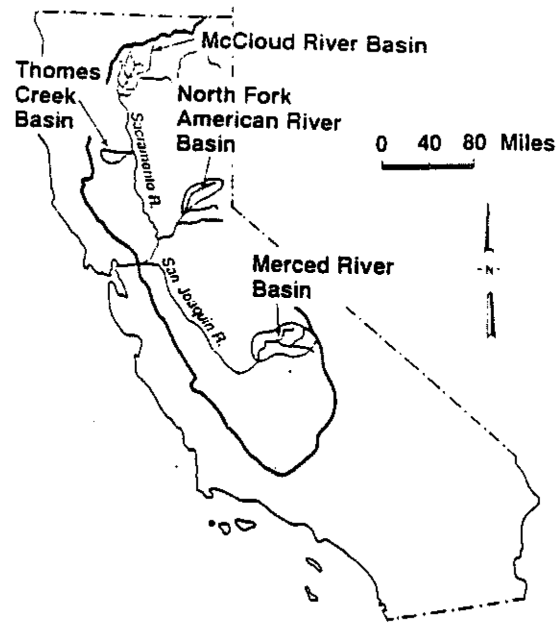

Figure 5.1. Locations of the Four Catchments Used in the California Study

In Step 1 of our approach, the model was implemented for those four catchments based on their historical records. Some "fine tuning" occurred during this step to make the model reflect what actually happens in each catchment.

In Step 2, the models were run for a relatively short time step. If you want to simulate snow accumulation and snow melt runoff, you need to use a daily or subdaily time step. In the California study, we started there and aggregated the results to obtain monthly runoff predictions.

In Step 3, we used a different kind of model. We analyzed stream flows for four relatively small "representative" catchments. However, we wanted to know what was going in for much larger river basins that feed a reservoir system (for which there were certain defined inflow points). To get that information we developed a stochastic (or statistical) model to relate the monthly flows from Step 2 to the reservoir inflows in the larger basin at the defined inflow points.

In Step 4, we employed still another type of model that simulated reservoir operation. These operations were modeled using a lengthy sequence of monthly reservoir inflows that came from Steps 1, 2, and 3. Those efforts allowed us to generate a sequence of flows that were essentially climate driven.

In Step 5, we changed the inputs (that is, the precipitation and temperature) to reflect alternative climates. The schematic of the process is shown by Figure 5.2. As you can see, there is a cascade of models involved.

The climate alternatives that we wanted to examine have already been discussed by Michael Schlesinger in his talk. There were alternative climates based on three GCMs. These same models were used in the EPA study. The three models used were developed at the Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL) and Oregon State University (OSU). The form of the model output that we used

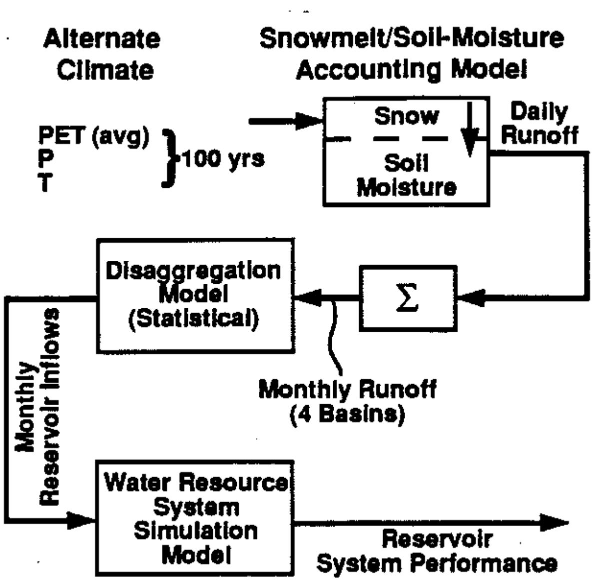

Figure 5.2. Process Used in Step 5 to Change Precipitation and Temperature to Reflect Alternative Climates

$$P'_{ij} = P_{ij} f_j$$

i = day index

j = month index

P_{ij} = historic precipitation

$$f_j = \frac{\bar{P}_j (2 \times CO_2)}{\bar{P}_j (1 \times CO_2)} \quad \text{(precipitation adjustment factor)}$$

$$T'_{ij} = T_{ij} + \Delta_j$$

T_{ij} = historic temperature

$$\Delta_j = \bar{T}_j (2 \times CO_2) - \bar{T}_j (1 \times CO_2) \quad \text{(temperature adjustment increment)}$$

Figure 5.3. Modification of Historic Precipitation and Temperature Data Used in Step 1

was for steady-state carbon dioxide doubling. We also did some work on a transient (nonequilibrium) climate change, but I will not discuss those results. The monthly average temperature and precipitation were estimated from the GCM output for an interpolated grid cell, which was more or less centered over the Sacramento-San Joaquin Basin.

Figure 5.3 shows how we altered the inputs to our model. We used historic precipitation and temperature data, and we altered data in a very simple-minded way. We said that if the GCM predicted that there was an average change of 3.5°C in January, then we took all the historic temperatures in January and incremented them by 3.5°C, which is an additive adjustment to temperature. To increment precipitation, we used the same idea except that we performed a multiplicative adjustment. In California as in most of the West, it turns out that are only about 3 to 5 months when that is going to make much difference. A 20% change in precipitation in January is much more significant than a 100% change in July, because 100% of a number that is near zero still is not very much.

Basically, that was the adjustment we made to obtain the altered sequences. We then developed the simulations. Two cases were analyzed; we analyzed historical conditions using the historic inflows, and we also simulated flows using historical meteorological data. The latter analysis formed what we term the "base case;" it removes any biases that might be introduced in the modeling chain. We then altered the precipitation and temperature to correspond to the carbon dioxide doubling scenarios from each of the GCMs; these formed the three alternative climate cases.

5.3 RESULTS

We can examine a number of variables that represent basin hydrology using this approach. For example, we can look at average snow water equivalent for the four small catchments we were interested in. We can examine mean streamflow for each month, mean evapotranspiration, mean soil moisture, and the annual flood series. Also, we can show statistics that represent the monthly performance of the reservoir system. The problem is not that we cannot show enough information; rather, it is that we have so much output that we have to make some selection. We can also look at variability of hydrological and other factors, which we have done somewhat. I will discuss those results, but I will preface that discussion with a comment on some sensitivity analysis we performed.

We made a model run to investigate the effects of the relative precipitation compared with the effects of changed temperature. That same issue was discussed by John Harte this morning. We investigated that issue by simply resetting the percentage precipitation adjustment (in Figure 3) to 1.0, so we used the historical precipitation and altered only the temperatures. We looked at another sensitivity run where, simply for comparison purposes, we created a climate similar to that in the decade of the 1930s.

Figure 5.4 shows mean (average) simulated snow water equivalents (water equivalent of snow on the ground) by month for one of the index catchments (Thomes Creek) for the base-case climate and three alternative climates. Qualitatively, we see the same kinds of results for all of the other catchments. The top dashed line in the figure is the mean snow water equivalent by month for the base case. (Hydrologists like to use the water year, which is measured from October to October.) Peaks in the snow water equivalent obviously occur in about March or April. All of the other lines, which represent carbon dioxide doubling, show a substantial decrease in the snow accumulation. The least decrease results from use of the OSU model. The GFDL and the GISS models show much more substantial reduction in snow water equivalent, but all of the models show the change to be large.

Figure 5.5 shows the key result from a hydrological perspective. This is what happens to stream flow (in particular, for Thomes Creek). The bottom dashed line is historical data. The shape varies a little for other catchments, but the shift does not. What you see is a dominant snow melt peak in the spring, a decline in stream flow in the summer, then extreme dryness in the summer and autumn under the current conditions. For the climates in which carbon dioxide doubles, there is much more runoff in the winter because precipitation falls as rain instead of snow; therefore, there is no storage of water as snowpack. Conversely, there is a substantial reduction in runoff in the spring and summer.

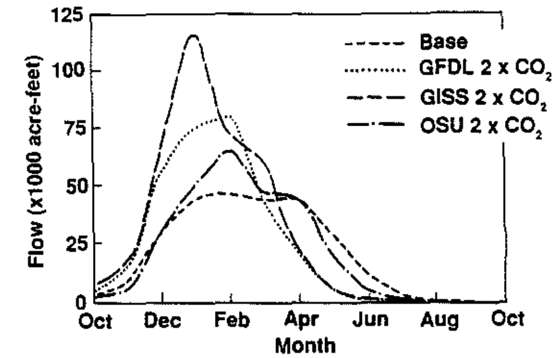

Figure 5.5. Stream Flows for the Thomes Creek Catchment

One other phenomenon that accompanies the shift of snow to rain is a change in flow frequency. Figure 5.6 shows flood frequency distributions for the McCloud River Basin catchments. The horizontal scale has the flood return period. The figure shows large increases in the flood frequency that are associated with the occurrence of rain rather than snow in warmer than normal winters. I should

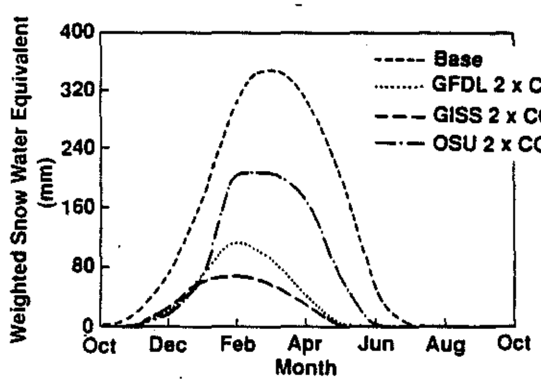

Figure 5.4. Snow Water Equivalent for the Thomes Creek Catchment

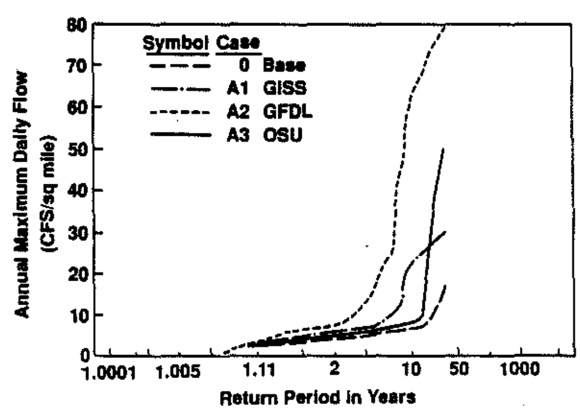

Figure 5.6. Flood Frequency Distribution for the McCloud River Basin Catchment

emphasize that this result is tied to the assumptions that were made to drive the models. In particular, we took the historical precipitation and temperature sequences and altered them, rather than changing the sequencing of events. One of the unresolved issues in assessing climate change effects is figuring out how storm sequences might change.

Figure 5.7 shows sensitivity results based on snow melt in the Merced River Basin catchment. The top dashed line is again a base case that essentially reflects current conditions. One of the alternative climates is a 1930s equivalent. The climate in the 1930s was a bit drier but not warmer than our present climate. The temperature change was not very much, at least for California. Those results come from, I think, about 10 stations that have been recording data for about 90 years. We obtained the equivalent alternative climate by averaging data from those stations.

Also shown in Figure 5.7 are two other lines that should be of interest. One is for the GISS model under carbon dioxide doubling conditions, which is the same as in Figure 5.4. We did the sensitivity test only for the GISS model. The other is a result for the GISS model where we reset the precipitation to current levels. What is important is that the difference between these two lines is much smaller than the difference between either of the GISS carbon dioxide doubling alternatives and the base case. This suggests that the results are being dominated by temperature and not by precipitation.

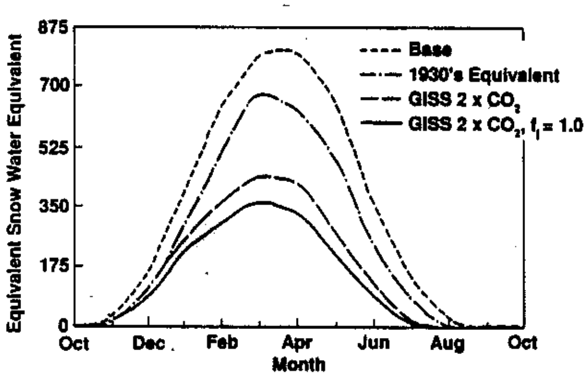

Figure 5.7. Results from Sensitivity Analysis Based on Snow Melt in the Merced River Basin Catchment

Similar things occur if you examine the stream flow as demonstrated in Figure 5.8. The broken line describes current conditions. These results are based on data for the McCloud River Basin catchment and the Merced River Basin catchment, which is at a higher elevation than the Thomes Creek Basin. The results are shown in Figures 5.6 and 5.7, respectively. The kinds of changes that occur are even more apparent in this catchment. With the solid line here, the 1930s analog (where temperatures were not warmer) follows the same seasonal distribution. There is, on average, just a little bit less runoff.

The other two experiments show a dominant shift in the distribution of runoff, and again you see a change here not only in the amount of runoff, but also in the shape of the annual flow distribution in these simulations, the distribution is clearly dominated by the temperature.

Figure 5.9a-c shows results for storage in one of the California reservoirs. Oroville Reservoir is the largest in the California State Water Project. In March, the reservoir is almost always full, and it does not make too much difference if the climate changes a little. Later in the year, however, differences appear. The horizontal axis is a probability scale again. The observations at the bottom that indicate lowest storages are from drought years. The model results tend to form a grouping in May, with only model storage changes for the OSU model, but more significant changes for the GISS and GFDC climate alternative. For May, we see rather substantial changes in the middle of the water storage

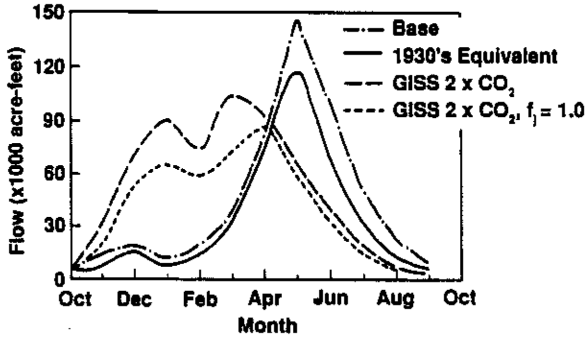

Figure 5.8. Results of Sensitivity Analysis Based on Stream Flow in the Merced River Basin Catchment

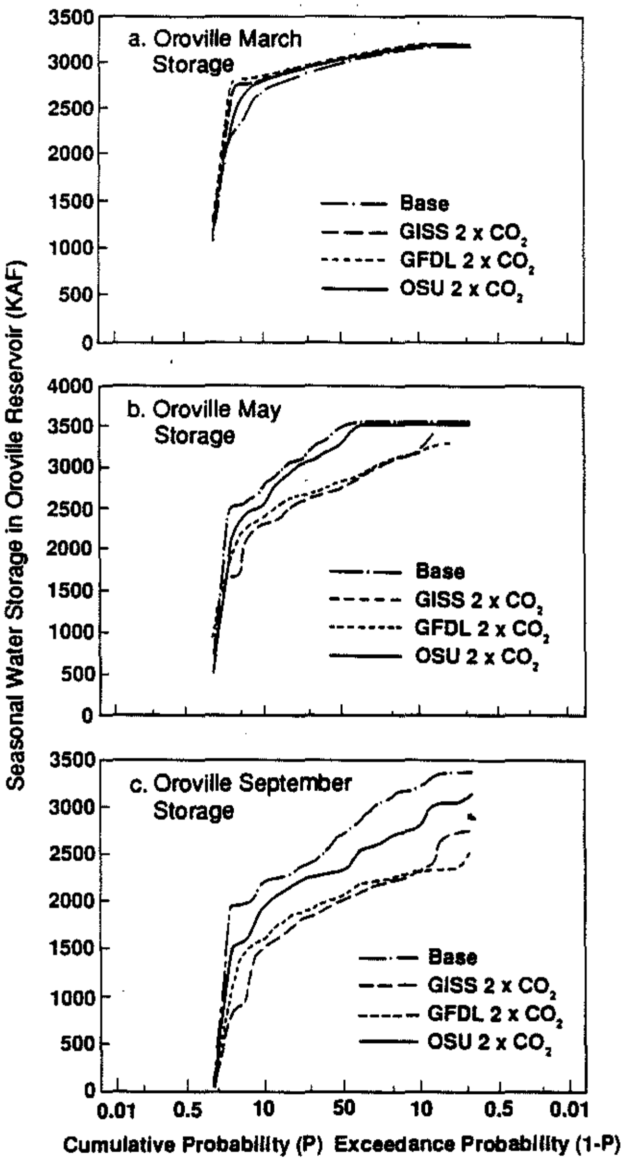

Figure 5.9a-c. Seasonal Water Storage in Oroville Reservoir

distribution, and by September (within-year), we see significant differences. This all has to do with the change in the flow distribution; runoff is plentiful in the winter but sparse in the spring anymore because the snow storage has been lost.

One of the things that was of concern in the EPA study was water deliveries, since the Sacramento-San Joaquin system is dominantly a water-supply-driven system, and the water is primarily used for agriculture. One could think of water-delivery reliability related to low probabilities. Figure 5.10 shows annual water delivery in thousands of acre feet (KAF), again on a probability scale. The figure shows substantial decreases in the amount of water that can reliably be delivered (for example, the water that could be delivered 98% of the time).

5.4 IMPLICATIONS FOR THE PACIFIC NORTHWEST

What can be said about Pacific Northwest hydrology based on the California study? One of the similarities between California and the Pacific Northwest is that we both have small reservoirs. One might think that Lake Roosevelt, which is formed by Grande Coulee Dam, is not a small reservoir, but when we are analyzing these problems, the variable that is important is the size of the reservoir storage relative to the mean annual flow. If that number is less than about 1, it means that those reservoirs are working primarily to store water within the year to reshape the flow of the annual hydrograph.

The same thing occurs in California where they have within-year reservoir systems. If you look at the upper Missouri or the Colorado River Basin, a different situation exists. There, they have over-year storage reservoirs and the annual total flow is much more important. But the redistribution of flow within the year is certainly going to dominate here in the Pacific Northwest. Certainly, if anything, Pacific Northwest catchments are at lower elevations than in California, so a few degrees change in the

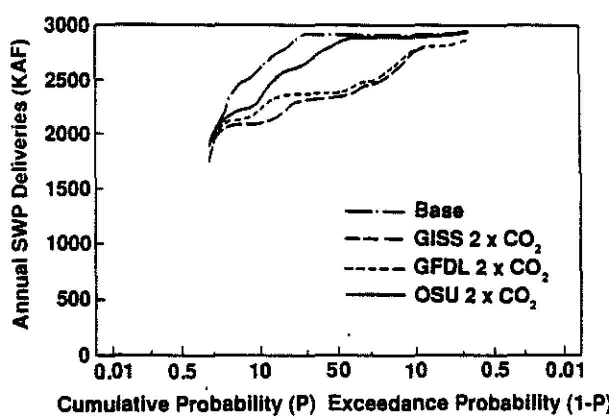

Figure 5.10. Annual Water Delivery for the Sacramento/San Joaquin System

temperature will even more dominantly shift the flow hydrograph towards winter runoff and away from snow storage. Therefore, some of these general inferences from the California study are potentially applicable to the Pacific Northwest. We will have a better idea about this, when we have the results of the analysis on the American River, which is currently under study, and perhaps some other catchments in the Pacific Northwest.

6.0 IMPACT OF GLOBAL WARMING ON ANADROMOUS FISHERIES OF THE PACIFIC NORTHWEST

Duane A. Neitzel, Pacific Northwest Laboratory, Richland, Washington

Can global warming be related to an effect on a regional resource? That is essentially what we are here to discuss today; particularly, the potential impacts to salmon and steelhead. What will happen to the salmon and steelhead, if the climate changes? And, then if we can assess or predict this potential impact, how can this information help the Power Council identify steps that the regional utilities can take to help mitigate the problem?

We just listened to Dennis Lettenmaier discuss what global warming could mean to the Pacific Northwest hydrological cycle. He presented his data from model predictions. The snow-melt-driven hydrological cycle could change its shape and timing (Lettenmaier et al. 1988). Water in Pacific Northwest streams and rivers will be warmer, won't be as plentiful, and natural fluctuations will occur at different times of the year.

All these changes are important in the life cycle of the salmon and steelhead.

Can these things happen, and can we assess the potential impact to the anadromous fishery? I looked at three sets of data to try to answer these questions: first, the life history of the salmonids; second, part of the archaeological record of the Pacific Northwest; and third, life history and environmental research of fisheries populations throughout North America.

6.1 SALMONID LIFE CYCLE

The salmonid life cycle and the suitability of the riverine habitat is closely related to the hydrological cycle. Water for the rivers and streams of the Pacific Northwest is stored in the mountains during the winter. During the spring, snow melts and large quantities of water enter the rivers. As the air temperature rises throughout the summer and there is less and less precipitation, stream flows decrease and water temperatures rise.

The salmonid life cycle has evolved to accommodate this cycle. Adults migrate upstream after the freshet. Nests are dug and eggs are laid in the fall as water temperature begin to decrease. Then as winter ends young salmonids emerge from the gravel and enter the rivers. After some time in the river, the young migrate to the ocean. Juvenile migrations to the ocean occur during the spring when the trip is aided by the increased flows of the spring freshet.

So we see the very close relationship between the salmonid life cycle and the hydrological cycle.

6.2 THE ARCHAEOLOGICAL EVIDENCE

Now we have to ask, can the climate and hydrological cycle change? We can look back into our history and see that the answer is yes. During the last 10,000 years there has been several periods in which the climate has changed. Archaeological data from explorations near Wells Reservoir in north central Washington provide evidence of the changes in salmonid habitat that are correlated with changes in the Pacific Northwest hydrological cycle (Chatters 1986).

Dr. J. C. Chatters at Pacific Northwest Laboratory has studied this historical record and describes a correlation between climate, stream flows, stream-side vegetation, sediment characteristics, and aquatic fauna, including salmonid populations. These data are in the geomorphologic (land forms), palynologic (fossil pollen and spores), and paleontologic records (fossil animals and plants). Figure 6.1 briefly summarizes some of these correlations.

8000 to 6000 Before Present (B.P.)

Five to ten thousand years ago (and especially six to eight thousand years ago) the area was dry and warm. Sagebrush steppe covered the river terraces,

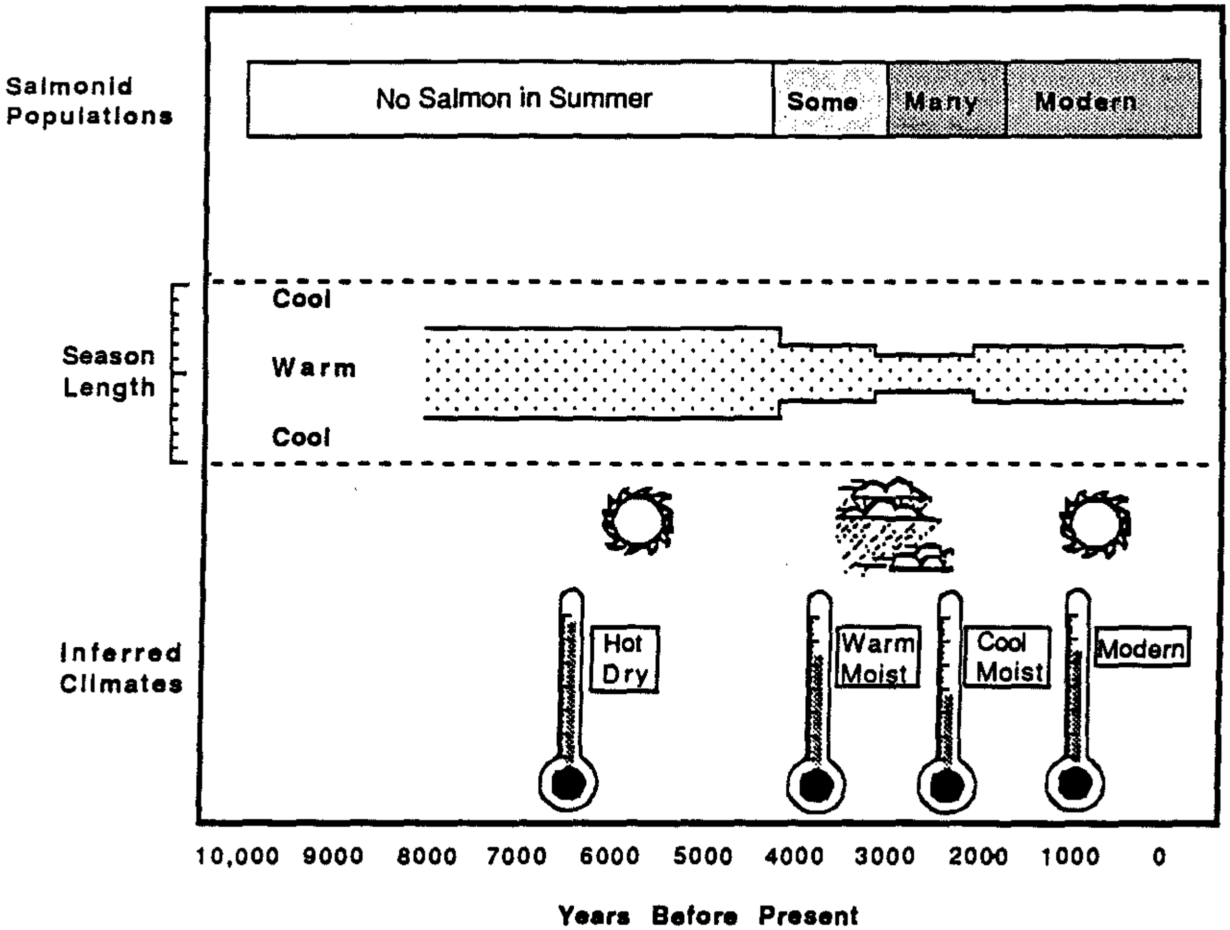

Figure 6.1. Correlation of Climate, Hydrological Cycle, and Utilization of Salmon Resources from Historical Data for North Central Washington State (modified from Chatters 1986)

plateaus, and mountains sides. The data indicate that the warmer season began up to a month earlier and probably continued until later than it does today. River sediments built up during this time. In general, rivers had low water levels and flowed over beds of gravel with extensive infilling of sands. Flooding was infrequent. The longer warm season initiated the spring melt earlier and brought it to an end in June. The lack of salmon bones in the summer encampments of this period indicates a difference in the timing of salmon runs between then and now. The seasonal distribution of water and water temperature probably caused this difference.

4350 to 3700 B.P.

The climate during this period was more moist and the seasonal temperatures were similar to what we see today. The rivers built up a more steeply sloping floodplain during this time. The distribution of mussel populations throughout this area indicates that the river bottoms were sandier. The buildup of the floodplain probably resulted from the increased frequency of major floods. Salmon were more plentiful during this period. The people who lived in the area were sedentary hunters and fishermen. They were especially adapted to or proficient in collecting salmon and suckers.

3300 to 2200 B.P.

This was a cool moist period that followed 300 to 400 years of arid conditions. Glaciers advanced in the mountains. The mussel gathering and utilization by the people living in the area was restricted. The annual melt-off apparently continued into August each year. The rivers were cold. Entrenchment of the river beds occurred during this time. Severe floods occurred infrequently. Rivers had gravelly beds and clear water. Salmon were among the most important animal foods of this period.

After 1000 B.P.

The environment was much as it has been in historical times. The rivers had clear waters and the bed consisted of clean gravel. The seasonal warm temperature period is lengthened. The salmonid populations are plentiful.

So, we see that climate change has happened and will probably happen again; caused by either human activities or natural occurrences.

Reconsider now our original question about potential impacts. Can we predict impacts to the anadromous fishery with what we know about fish today?

6.3 THE EVIDENCE FROM EXTANT FISH POPULATIONS

Last fall (1988), the American Fisheries Society conducted a global climate change seminar at their annual meeting (American Fisheries Society 1988). The seminar was organized by Henry A. Reiger, professor of fisheries at the University of Toronto, and the participants discussed climate change and fisheries. The contributions of the participants gives us an idea of the types of impacts that could affect the anadromous fishery in the Pacific Northwest.

The habitat used by salmonids is vulnerable to climate warming. Not all the evidence is directly related to salmonid research; however, indirect evidence does prove interesting. Charles Coutant at the Oak Ridge National Laboratory has described the habitat constraints for stripped bass resulting from increased water temperatures and decreased dissolved oxygen concentrations. Ken Frank with the Canadian Department of Fish and Oceans has described carbon dioxide changes in terms of changing the location, composition, and recruitment characteristics of fish populations in Canada. The changes he describes are related to the current environmental requirements of Canadian freshwater fishes. Brian Shutrer and John Post at the University of Wisconsin examined fish at the northern extent of their range. Further extension of the smallmouth bass and yellow perch is limited in some places by winter starvation. However, with climate warming these populations could extend further north displacing cold climate adapted fisheries.

David Hill and John Magnuson at the University of Wisconsin stated that fish are sensitive to increased temperatures because their physiological processes are functionally dependent on temperature. They predict that climate change could affect prey consumption and growth of effected populations. This type of impact could be very important when considering the predator populations downstream of the Columbia River dams. John Holmes at the University of Toronto is using cold water stream fish as "early indicators" of climate warming because of their sensitivity to habitat change. This conclusion or finding is supported by the contention of Edward Kott and Alison Babin at Wilfrid Laurier University. They predict the best species to monitor warming trends are "predominantly" riverine species that breed in streams. These fish will be affected early if a climate warming change occurs.

Donald Meisner at the University of Toronto has studied the spawning habitat of salmonids and the relationship to groundwater warming. If you look at the model that Meisner et al. (1988) developed from some work that Brown (1970) and Williams (1970) did in Canada and Alaska, we see an interesting correlation between air temperature and ground temperature (Figure 6.2). At the surface, we see the greatest annual fluctuation and as we go deeper, the difference between the maximum and minimum decreases. If you go deep enough, you reach the point where maximum and minimum are equal. This is the neutral zone or level of zero annual amplitude. In severe climates at high latitudes where the annual temperature range is large, the depth to which temperature fluctuations occurs is at its maximum. In the tropics the neutral zone is shallow

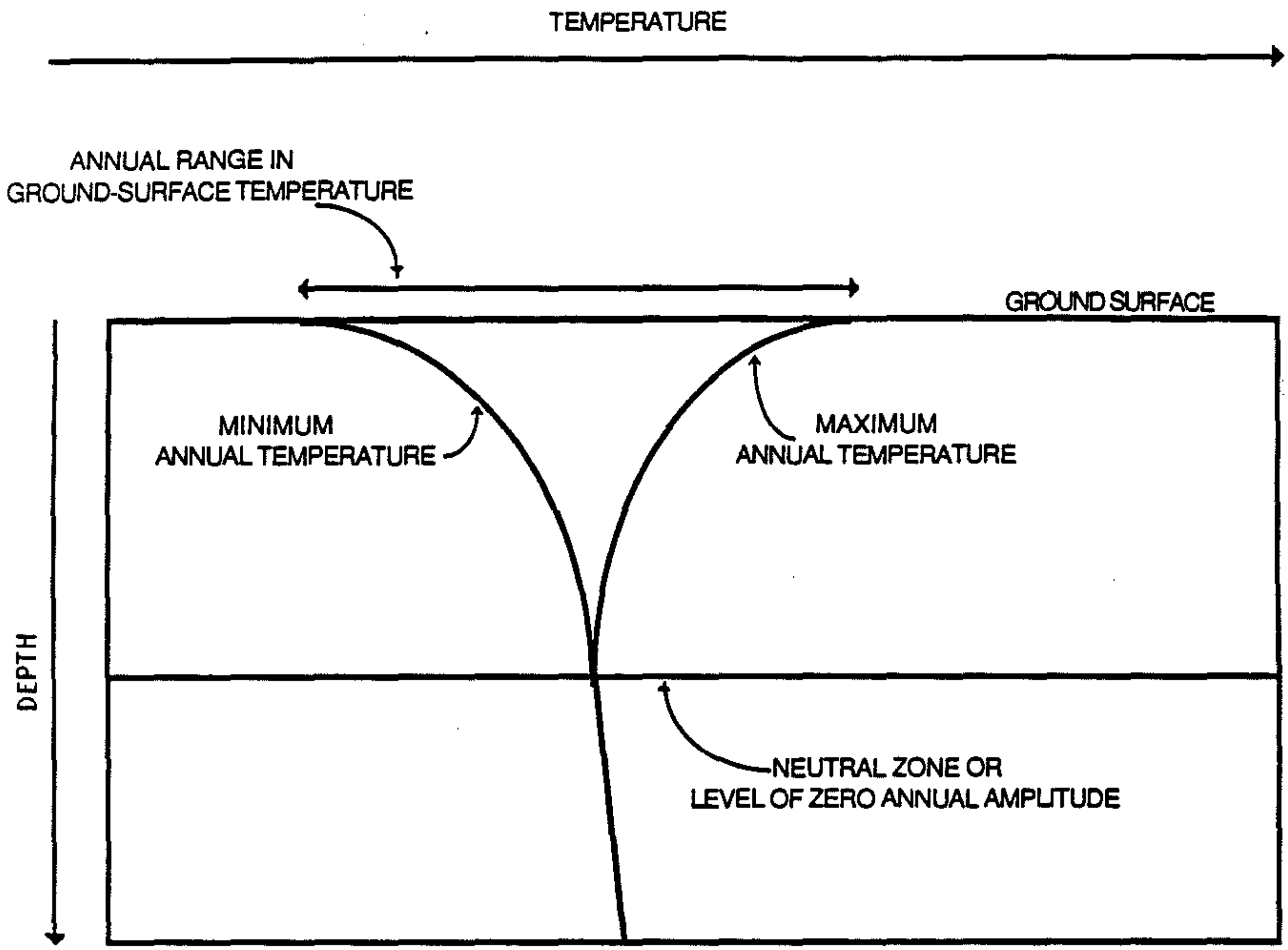

Figure 6.2. Correlation Between Air Temperature and Ground Temperature (Meisner et al. 1988)

(approximately 20 feet) and the range is a few degrees. Near the poles the depth is greater than 50 feet and the range is greater than 30°C. In the temperate latitudes the depth is approximately 50 feet and the range is approximately 25°C.

What does all this have to do with climate warming and impacts to anadromous fish? Salmonids at the bounds of their thermal environment are sometimes "protected" by groundwater discharges which keep stream waters cool. Meisner et al. (1988) used a hydrometerological stream temperature model to simulate loss of brook trout habitat due to climate warming. He predicts a 40% loss of spawning habitat in areas where groundwaters protect the thermal characteristics of the spawning habitat. There are some very complex interactions that have to be thought through to assess climate warming and the potential impacts to salmonids.

Burton Ayles at the Department of Fish and Oceans in Winnipeg wrapped up the discussion of climate change and fisheries population by saying that when we assess this information we cannot assume that the long term aquatic environment is stable. Fisheries policy and implications for protection and enhancement of fisheries habitat must provide for possible changes in the climate.

We can see the potential effects of global warming on the fishery from the mathematically modeled data, the archaeological data, and the natural history data.

Before we proceed and examine what might be done with this information, let us briefly look at the Power Council's Fish and Wildlife Plan.

This plan relies heavily on the physical properties of the Pacific Northwest environment to protect and enhance salmonid populations.

- Section 200 - The framework for protecting and enhancing salmon and steelhead populations is a plan to increase and improve fish production, to provide safe passage during migration, and to manage harvest effectively. All are needed, and to complicate this Herculean effort, Pacific Northwest electricity consumers are assured of an adequate, efficient, economical, and reliable power supply. These goals all mean plenty of water, and as we have already heard today, global warming can mean less water, or at very best, varying amounts of water at different times of the year.

- Section 300 - The combination of reduced flows and the greater cross-sectional area of the river due to reservoir storage slows the juvenile fish as they migrate from their area of origin to the ocean. This increase in travel time affects the ability of the juvenile salmon to make the transition from freshwater to saltwater and increases their exposure to predatory fish and birds. Reduced flows also endanger juvenile salmon by raising water temperatures, altering water chemistry, and increasing susceptibility to disease.

To solve this problem, spring flows are increased in the Columbia and Snake rivers. This is known as a water budget or in the Pacific Northwest "the water budget." The water budget is a block of water set aside for fish and released during the spring migration to create and "artificial freshet" that speeds juvenile fish to the ocean. The water budget is based on the fact that an adequate amount of hydropower is available even in historical low-water conditions.

- Section 400 - When hydroelectric dams were built in the Northwest, many people believed that providing adequate upstream passage over the dams for adult fish returning to spawn was sufficient to sustain salmon and steelhead runs. Research has shown that juvenile salmonids headed downstream also suffer high mortality rates as they encounter the dams. Changes in pressure and injury from turbine blades as fish pass through the dams can kill or injure the fish. Even when fish pass through or over the dams alive, they may be stunned or disoriented and become more susceptible to predators and disease.

The Power Council has taken a number of actions to reduce mortality rates of juvenile fish. Protection measures include installation of bypass systems at the dams, requiring that dam operators spill sufficient water at the dams to guarantee a specified level of fish survival, and adopting measures to transport juvenile salmon around some dams. These protection measures include a "share the wealth" concept that provides for fish protection even during critical water years.

- The Other Sections - I just touched on three sections of the Plan. It quickly becomes apparent that water is the key to the protection and enhancement of the anadromous fishery in the Pacific Northwest. In addition to the sections just described, the Plan includes other provisions. Protection and enhancement of upstream migrating adults is provided by fish ladders with appropriate spill criteria and attraction waters to ensure their effectiveness. Enhancement is advanced with wild, natural, and artificial propagation measures. Suitable flow, temperature control, and habitat improvement are important to or required by this remedy. The success of "off-site mitigation" is dependant on water. Additional storage, adequate passage facilities and water, and adequate flows are important to the Yakima River Basin enhancement.

6.4 MANAGEMENT PLANNING

So what can be done about climate warming? Fisheries resource managers are not going to change greenhouse gas emissions with fisheries policy. Environmental policy is not directed by fisheries alone. Does this mean the protection and enhancement of the fisheries and mitigation of hydroelectric impacts to the fisheries will be negated by climate changes?

I don't think so. However, fisheries policy has to remain flexible, even when facing long-term, hard-to-define environmental changes. This fact (flexibility) probably defines the real need for assessing potential effects of global warming on the anadromous fishery.

First, we need to determine what impacts might occur; maybe more important is to determine what impacts could occur given a level of change. If we get a certain amount of warming in the climate, what will that mean for water temperatures, flows, and annual water patterns. We can predict these hydrological and habitat data with models. Then we can assess the potential impact given a potential change. By assessing a range of potential changes, we can develop set of "power curves." We will know how much change in climate is required to adversely impact the anadromous fishery.

If the potential impact falls within a scenario of reasonableness, then plans to mitigate for the change and plans to protect the resource will have to be studied.

What kind of things can be done? There is an interesting proposal in the Washington State legislature right now that would change the balance of fisheries policy emphasis between sports and commercial fishing. How does this relate to global warming? Well, some regions are planning for long term changes in their fisheries populations by emphasizing the sports fishery over the commercial fishery. This is being implemented in the Great Lakes salmonid fishery. Dr. Harold Tanner, from Michigan State University, is a advocate this type of planning. He says that sports fishing requires less fish, less habitat, and has less impact on the species of interest. Therefore, emphasizing sports fishing over commercial fishing is a more flexible management plan.

Another idea that could be considered to protect the anadromous fishery is a near ocean hatchery system. This runs counter the hatchery and outplanting planning of the Fish and Wildlife Plan, however if annual water patterns change enough, there may not be enough water to manage the subbasin planning that is working so well today.

Conservation and allocation of water will become more and more important. Planning may have to occur for water conditions that are less than those that we see during the historical low water years.

6.5 CONCLUSIONS

We can see that global warming could change the anadromous fishery in the Pacific Northwest. However, these concerns are 20, 50, maybe 100 years in the future. There is a lot of planning in the Pacific Northwest to protect and enhance the anadromous fishery. However, this planning is the result of actions taken 50 to 100 years ago. We need to look 50 years ahead and see what should and could be done now. We should identify those potential impacts that are probable, and make sure the Power Council's Fish and Wildlife Plan contains the flexibility to deal with these potential changes.

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7.0 GLOBAL WARMING: WASHINGTON STATE POLICY ISSUES

Booth Gardner, Governor of Washington
Olympia, Washington

I am pleased to welcome you all to Olympia and to commend the Power Council for holding this important symposium on global warming and the greenhouse effect.

This morning you heard a number of leading scientists discuss the technical issues surrounding the greenhouse effect. I won't try to be a scientist. Instead, I'll focus on several broad policy issues raised by the scientific debate over global warming. In particular, I'll explore what state policy makers should do about the greenhouse effect, and why the work of the Power Council offers us a good model for future action.

You may be asking: Why is the Governor of Washington taking an interest in such a global issue? First, I believe protecting our environment makes sense for its own sake, and it also is in the vital economic interest of Washington and the entire Pacific Northwest.

In the last 10 years, the global economy has become increasingly competitive. This trend will continue, especially in the high technology and information industries that compete vigorously for market share and for skilled workers.

The Power Council has been a leader in preserving the Pacific Northwest's heritage of low cost electricity, which provides a competitive edge for existing and new businesses in the Northwest. However, in terms of attracting new businesses and skilled workers, the quality of our environment is even more important. The Washington State Economic Development Board, in its recently published long-term economic development strategy for the state noted:

> "Today, a quality environment is an economic asset. It is also an ecological necessity."

The Pacific Northwest, with its clear air and clean water and its mountains, forests, deserts, and sea shores, has historically enjoyed a clear edge in attracting these increasingly important new businesses and skilled workers. Preserving and enhancing that edge is essential for our economy and our survival.

Returning specifically to the greenhouse effect, 4 years ago the World Meteorological Society warned:

> "We are conducting one giant experiment on a global scale by increasing the concentration of trace gases in the atmosphere without knowing the environmental consequences."

Some of the environmental consequences in Washington alone could be severe:

- Miles of our state's shoreline, wetlands, and the resources they support could be damaged, perhaps beyond repair.
- Washington's valuable evergreen forests might not adapt to a rapidly changing climate--a situation that could have devastating effects on our state's quality of life and its valuable forest products industry.
- In an ironic twist, global warming could decrease this region's winter snowpack, cutting into our hydroelectric system's power output and speeding the day when we may need to construct thermal plants--plants that today are a major contributor to the greenhouse effect.

This last example brings me back to what I believe is a key point: Our choices about energy are frequently at the root of our environmental problems.

If the greenhouse effect proves to be the most widespread and challenging environmental problem caused by our energy choices, it won't be the first.

- Once abundant, the Northwest's salmon and steelhead runs are now greatly diminished, largely due to hydroelectric project development in the Columbia Basin.

- Acid rain, caused by burning high-sulfur coal to produce electricity, is killing forests and lakes in the eastern United States, Canada, and Europe.

- The recent oil spill off our coast killed hundreds of sea birds from Oregon to British Columbia and reminds us of another danger associated with our use of fossil fuels.

- Clearly, the greenhouse effect and these other environmental problems are sending us an important message: We must begin to develop an integrated energy and environmental policy--at **the state level, at the national level, at the international level, and for issues like the greenhouse effect, at the global level.**

Given the possible impacts to our environment, it would seem that taking this action would be easy, but many rationalizations can be used as an excuse for inaction.

- For one, it is an easy step to go from thinking "it's everyone's problem" to thinking "it's no one's problem." Even if the State of Washington took aggressive action to reduce production of carbon dioxide, we only account for 0.25% of the world's carbon dioxide from fossil-fuel consumption. Taking this thought process one step further, even if the United States were to take aggressive action, we only account for 25% of the global total.

- The belief--or should I say myth--that economic growth and increasing energy use must go hand-in-hand is deeply rooted in our society and is another factor leading to inaction. In developing nations that are struggling to expand their economies, this belief may be particularly strong.

- Finally, as you heard this morning, there is still honest scientific debate: Are we really experiencing global warming caused by the greenhouse effect? If so, how severe will the problem really be? Just as certainly as last summer's heat wave was cited as proof of the greenhouse effect, last week's cold snap will be cited as proof there is no such thing.

Some may ask: Why do anything before we know for certain that there is a problem? But, if we wait the 10 to 20 years it could take to resolve the scientific debate, it may be too late. Fortunately, there are things we should be doing right now, for other reasons, that will also reduce the magnitude of global warming.

- Here, at home in Washington, the best thing we can do is to use energy--especially fossil fuel--more efficiently. There are many things we can do that would cut our energy costs, decrease our dependence on imported oil, and improve our quality of life by reducing traffic congestion and improving air quality.

- One area on which we should focus our efforts is transportation, which is the biggest source of carbon dioxide in Washington and the Pacific Northwest. We can do this by:

  - increasing fuel economy standards rather than relaxing them, as has been done over the last 3 years

  - making greater use of car pools, van pools, and buses

  - making our overall public transit system more efficient

  - looking at ways to reduce the demand for transportation, through better land use planning and innovations like telecommuting.

  These actions would not only reduce carbon dioxide production but would reduce air pollution and traffic congestion as well.

- Beyond transportation, we can make our industries, our businesses, and our homes more energy efficient. This will reduce fossil fuel use, save energy dollars, and delay, or perhaps eliminate the eventual need for building new power plants--power plants that are currently slated to burn fossil fuel to generate electricity. That is one of the reasons I support efforts to make the Power Council's Model Conservation Standards part of Washington's building code. It's the kind of action that we know is effective and best done at the state level.

Our recent experience with energy efficiency disproves the belief that economic growth and increasing energy consumption must go hand in hand. In Washington, we have been successfully holding energy use per dollar of economic activity more or less constant for several years. If we used energy now as we did in 1972, we would be spending $3 billion more each year on energy, and producing 40% more carbon dioxide--30 million tons more. But we are not, and that is a significant accomplishment.

Improving energy efficiency here in Washington, in the rest of the nation, and throughout the world, will buy us time--time to resolve the debates surrounding the greenhouse effect and time to develop energy resources that emit very little carbon dioxide. Such improvements would also benyefit our economies and our environment in many other ways. That sounds like a win-win proposition to me, no matter what the reality of the greenhouse effect turns out to be.

Will starting out here in the Northwest really make a difference? At the beginning of my talk I mentioned the work of the Power Council as a model for future action on the greenhouse effect. It was the pioneering work of the Power Council that made the Northwest seriously look at efficiency as a new source of electricity. Clearly, the approach used by the Power Council can also be applied to fossil fuels.

The work of the Power Council is a good model for action in another more important way. It shows how actions, started at the local, state, and regional level and involving the public in the decisions, can make a real difference in solving energy and environmental problems.

I believe we can learn from this. Starting right now, we can take the first incremental steps toward addressing the greenhouse effect. We can make progress, and we can set an example for the rest of our country and the world.

It has to start somewhere.

8.0 GREENHOUSE GASES AND ELECTRIC POWER RESOURCES

Gordon J. MacDonald, The MITRE Corporation
McLean, Virginia

Before discussing some of the policy issues connected with electric power generation, I will review the overall development of the greenhouse issue. For even when looking at regional issues, one has to place them in the larger national and global context.

8.1 INTRODUCTION: ENERGY USE

The growth of world energy use is shown in Figure 8.1, which shows the amount of carbon dioxide introduced into the atmosphere as a function of time. Over a 130-year time period, the rate of growth of carbon dioxide emissions has been about 4.4% per year. The amount of carbon dioxide released into the atmosphere reflects the unfolding of history; World War I, the Great Depression, and World War II correspond to periods when releases of carbon dioxide decreased. As post-World War II economic recovery took place, economic growth resumed, and carbon dioxide releases began increasing again by about 4.4% per year. The long period of stable growth continued up to 1973, when the Middle East oil embargo occurred and economic growth slowed. The slowdown continued until about 1983 or 1984, when the growth rate again resumed at about 3.0% per year.

The growth in energy use has not proceeded uniformly among all fuels. As Figure 8.2 shows, for a long while, the growth was primarily in oil use. After the oil embargo, the use of oil leveled off, then decreased, and then, as prices again began to fall, increased once more. The use of coal, after a long period of almost no growth, is now on the rise and is globally the most rapidly growing fuel. Based on the preliminary figures for 1988, growth in the use of coal is currently a little over 5% a year based on the preliminary figures for 1988.

The distribution among nations of where these fuels are used has changed dramatically, as shown in Figure 8.3. The percentage of fuel-derived carbon dioxide emissions produced by the United States, Canada, and Western Europe has decreased. There has been a relative increase in the Soviet Union and in Eastern Europe, and a very rapid increase in the developing world. The increases have occurred over a long period of almost constant growth. The centrally planned economies of Asia--China, North Korea, and North Vietnam--have also increased their use of carbon-based fuels recently. These changes in the historical distribution of fuel usage have a number of implications for energy planning if we are going to deal with the greenhouse gas emissions, particularly carbon dioxide. Among these is

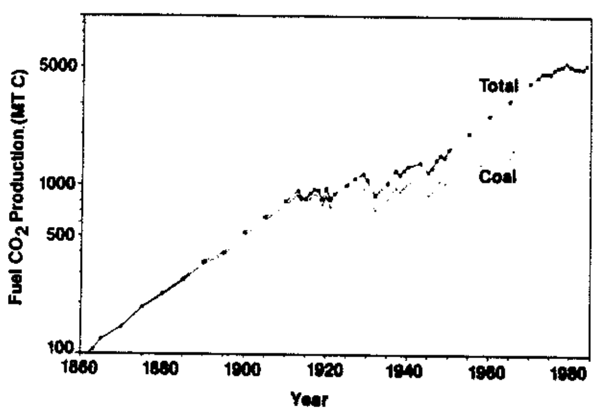

Figure 8.1. Historical Variations in Carbon Dioxide Emissions from the Burning of Fossil Fuels (data from Rotty and Kealing)

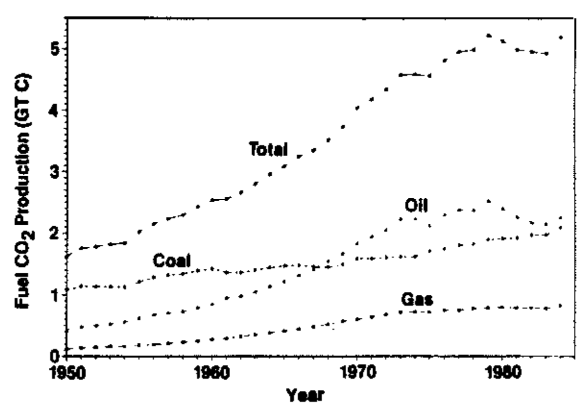

Figure 8.2. Variations in the Contribution of Various Fuels to Global Carbon Dioxide Emissions

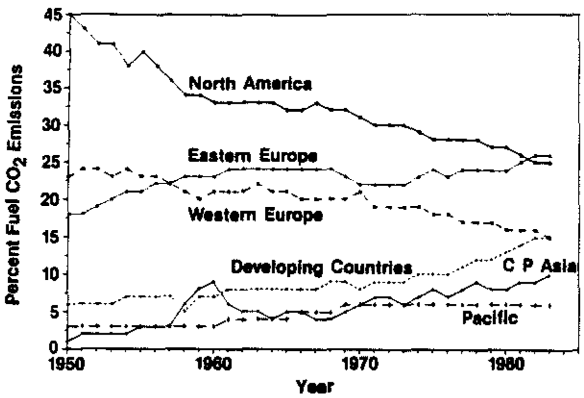

Figure 8.3. Regional Distribution of Carbon Dioxide Emissions

the need to recognize very clearly that not all fuels are alike. How much carbon dioxide is placed in the atmosphere depends on the ratio of hydrogen to carbon in the fuel that is used. A high ratio of hydrogen to carbon--for example, 4 to 1, as in the case of methane--delivers a lot of energy per unit of carbon dioxide emitted. Table 8.1 shows that the emission rate for methane is 13 kilograms of carbon per billion joules of energy or, equivalently, about 1,000 Btu. For hydrogen-poor fuels the ratio is higher, and coals, having relatively little hydrogen per carbon atom, emit almost twice as much carbon dioxide per unit of energy. These differences in emission ratios underline the significance of the shift in the use of various carbon-based fuels that is occurring worldwide. Coal is the most rapidly growing of the fossil fuels, and at the same time, it is the fuel that puts out the greatest amount of carbon dioxide per unit of energy delivered.

A further point is that when one of these feedstock fuels is converted to another form of energy, the total amount of carbon dioxide emitted into the atmosphere increases significantly. For this reason, some of the synthetic fuels are high carbon dioxide emitters (see Table 8.2). During President Carter's administration, a very large program was started to produce synthetic fuels from coal. At the time, there were several reasons advanced for those measures, including energy security and the need to assist the economically depressed areas in the country, such as West Virginia, regions in Illinois, and elsewhere. At that time, the amount of carbon dioxide in the atmosphere was not an issue. I did testify before congressional committees in 1978, 1979, and 1980 in an effort to spotlight the point that what is now called the "greenhouse effect" should be taken into account in energy decisions. The counter argument, and an argument that will be given over and over again, is that we are going to build only a few synthetic fuel plants, and they will produce only a little bit more carbon dioxide, and that, compared with the global level, the additions make no difference.

Table 8.1. Carbon Dioxide Emissions from the Direct Combustion of Various Fuels

Fuel	CO^2 Emission Rate kg $C/10^9J$	Ratio Relative to Methane
Methane	13.5	1
Ethane	15.5	1.15
Propane	16.3	1.21
Butane	16.8	1.24
Gasoline	18.9	1.40
Diesel Oil	19.7	1.46
Number 6 Fuel Oil	20.0	1.48
Bituminous Coal	23.8	1.73
Subbituminous Coal	25.3	1.87

Table 8.2. Carbon Dioxide Emissions from the Production and Burning of Various Synthetic Fuels

Fuel	CO^2 Emission Rate kg $C/10^9J$	Ratio Relative to Methane
Shale Oil		
In situ 28 gal/ton shale	48	3.5
High temperature 25 gal/ton shale	66	4.9
High temperature 10 gal/ton shale	104	7.7
Liquids from Coal		
Sasol technology; Eastern coal	42	3.1
EXXON donor solvent; Eastern coal	39	2.9
Gasoline from methanol from coal	51	3.8
High-Btu Gas from Coal		
Lurgi	41	3.0
Hygas	40	3.0
Methanol		
From natural gas	21	1.5
From coal	36-44	2.7-3.2

That is an erroneous argument, because we are dealing with large impacts made up as a sum of small increments, and those additional little bits of carbon add up very rapidly.

Another important point is that as soon as investment begins in a capital intensive industry such as synthetic fuel plants, an infrastructure and a momentum are established. It is very difficult to turn back once those initial investments have been made; the industry has made commitments, and the customers are expecting fuel from those sources. The synthetic fuels program eventually floundered, not on environmental grounds, but on strict economic grounds. Because fuel must be consumed in order to produce a synthetic fuel, the synthetic fuel is bound to be more expensive than the original fuel or feed stock. That simple underlying economic fact was not considered by the proponents of synthetic fuel plants.

Currently, there is great enthusiasm for another synthetic fuel, methanol. Methanol is being supported by California as an appropriate fuel for automobiles. The advantage claimed for methanol is that it will be effective in lowering carbon monoxide levels and ozone oxidant levels in urban regions. The state is well on its way to enacting a requirement that a certain fraction of service stations provide methanol as an alternative fuel, despite testimony by myself and others who raised issues like those outlined above.

As Table 8.2 shows, methanol is about 1.5 times more carbon dioxide intensive than natural gas (that is, it is about equivalent to gasoline), so the tradeoff with gasoline seems small. But for methanol proponents, the eventual goal is to make methanol out of that abundant resource, coal, and thus, revive the coal fields in West Virginia. The principal advocates of coal-derived methanol within the Congress are from that state. The greenhouse impact of such a program would be the emission of 2.7 to 3 times as much carbon dioxide per unit of energy produced.

The advocacy of methanol by a single state illustrates how every energy decision has long-term climatic consequences, and highlights the importance of evaluating and weighing energy choices with greenhouse considerations in mind. There may be circumstances where climate considerations can rightfully be overridden, but they should always be examined openly.

8.2 U.S. EMISSIONS

Table 8.3 shows that the United States produced 1.4 gigatons of carbon out of a global total of 5.5 gigatons. The United States puts out a little over one-fifth of the world's total carbon. What are the sources of carbon dioxide in the United States? The largest single source are electrical utilities. The second largest source is transportation, and as the breakdown by fuel type shows, the electrical utilities that burn coal are second only to automobiles burning gasoline as a single source. If the same breakdown were done globally (we cannot do that because the data are not available), we would probably find that electrical utilities would have a somewhat higher fraction globally than it does in the United States, and transportation a somewhat lesser fraction.

8.3 THE ROLE OF ELECTRIC POWER

Given the large carbon contribution from coal-fired electrical utilities, what other options are available to produce electricity? First, we know that if electricity is generated by hydroelectric or nuclear technologies, there are no emission problems (provided that we ignore for the moment any fossil fuels used in building the dams or the nuclear plants

Table 8.3. Estimated Carbon Dioxide Emissions in the United States by Sector of Economic Activity and Fuel Type (millions of metric tons)

Sector/Fuel	Coal	Natural Gas	Petroleum	Total	Percent
Residential/ Commercial	4.8	106.6	57.6	169.0	12.3
Industrial	74.3	106.7	126.1	307.1	22.4
Transportation	–	7.8	414.4	422.2	30.8
Electric Utilities	392.4	47.6	32.4	472.4	34.5
Totals	471.5	268.7	630.5	1370.7	–
Percent	34.3	19.6	46.0	–	100

and the support facilities). We also do not generate carbon dioxide from solar and certain other nonfossil-fuel sources of electricity. Looking at current technology, new plants using a natural gas combined-cycle can be expected to produce at a thermal-to-electric efficiency of about 43%, as shown in Table 8.4. The corresponding number of kilograms of carbon emitted per kilowatt hour is a little over a tenth as large as for a conventional gas turbine; for a new oil-fired plant it is twice as large. A conventional, but new coal-fired plant, as the table shows, emits twice as much carbon as the combined cycle plant. Advanced fluidized beds give some slight improvement in terms of carbon dioxide emitted, but much of the greenhouse benefit derived from their increased efficiency is lost because limestone is used, and carbon dioxide is emitted when the limestone is calcined.

8.4 POTENTIAL POLICIES

Where does this leave us then in terms of steps that need to be taken--at least within the United States, but ideally worldwide--to help curb emissions of carbon dioxide? First, without any question, the least-cost solution is energy efficiency. This has been shown to be true in transportation, electricity generation, and elsewhere. However, in this country, we are taking directions away from increased efficiency. The Corporate Average Fuel Efficiency (CAFE) standards were never fully implemented; they were, in fact, relaxed. At the federal level, the whole issue of building standards has been a forgotten area. I am, of course, delighted to learn of the attention and the seriousness of purpose that the Power Council is giving to that issue, because I think it is one of the key means of moving ahead with the attempt to increase both energy efficiency and economic efficiency, and to reduce climate change.

Table 8.4. Carbon Dioxide Production in Generating Electricity

System	Unit Efficiency (%)	Carbon Dioxide Released (kg C/kWh)
Natural Gas Combined Cycle	43	0.13
New Fuel Oil-Fired Plant	35	0.20
Advanced Fluidized Bed Coal-Fired Plant	37	0.23
New Coal-Fired Steam Plant	34	0.25

Second, with respect to alternative power sources, I believe that in the longer term, nuclear power must play a role. With nuclear power, the difficulty is one of solving problems that we are well acquainted with. I believe we can deal with the issues surrounding both safety and high-level waste disposal, which have been handled much better in other countries.

Third, natural gas must be used more effectively throughout the energy economy. Natural gas, despite frequent stories to the contrary, is not a vanishing resource. It is, in fact, a very large resource. I could give detailed evidence that natural gas is present in greater abundance than coal, a fact that is only beginning to be recognized. The large abundance of natural gas is in unconventional sources, particularly hydrates.

And fourth, we must deal with the issues regarding the other greenhouse gases. For chlorofluorocarbons, steps have been taken at the international level. The requirements that have been adopted by the industrialized world must also be expeditiously applied to the developing world and directed toward a complete phaseout of chlorofluorocarbon production.[a] Of all the greenhouse gases, methane is perhaps the most difficult to control because it has many sources, and for many of the sources, attempts to control releases might be viewed as intrusive. Finally, ozone in the lower atmosphere is an important greenhouse gas. Enforcing the ozone and carbon monoxide standards is a very important way to get the regional ozone contribution to the greenhouse effect under control.

8.5 QUESTIONS AND ANSWERS

Question: We keep hearing in the electric industries about the great virtues of the competitive market

(a) Editor's note: In early March, 1989, the governments of the Peoples Republic of China, Japan, and India were resisting early phaseout of chlorofluorocarbons without commensurate compensation.

and about bidding for electrical resources. Recently, for example, the Virginia Electric and Power Company acquired a couple of thousand megawatts of what I was led to believe was small coal-generating capacity. Would you please comment a little on the carbon dioxide effects of small thermal resources in cogenerating facilities? Does it make things better; does it make them worse; or should we even worry about it?

Answer: It makes things worse and I think we should worry about them, for the very reason that we talked about. Virginia Power feels that it is just a very small additional burden that they can deal with some other way. I think each one of those decisions needs examination just in that light, and the spotlight should be thrown on it. If Virginia Power decides to go ahead with this, it is going to increase the carbon dioxide burden, or the carbon dioxide contribution to the global burden by the United States.

Question: Do these smaller plants tend to contribute more carbon dioxide than the larger plants?

Answer: The smaller plants tend to run at somewhat lower efficiencies. And very definitely, they tend to emit more carbon dioxide than larger plants.

Question: I want to make sure I understood you correctly. Are you saying that methanol, when mixed with gasoline, has no measurable difference in emissions from straight gasoline?

Answer: If you derive the methanol from a biological feedstock (for example, corn or some other grain), you actually are better off from a carbon dioxide standpoint, because you can regrow the corn. That is not true if you are producing it from natural gas. The difficulty is that ethanol is produced from grains, not methanol. The difficulty with ethanol, as we have learned, is its enormously high price. You could not get fuel at under about $2 to $2.50 a gallon from ethanol. Even with the current grain subsidy, methanol, which is the current fad under discussion and the subject of legislation on alternative fuels, is a different story. It is approximately equivalent to gasoline in carbon dioxide impact if it is derived from natural gas. The alternative argument is, "Why don't you just use natural gas in the first place to run your car?"

Question: Do you see any method of increasing the efficiency by increasing the costs, such as by taxing?

Answer: Yes, I have been a longtime advocate of an across-the-board carbon tax. The tax that I have advocated is essentially about a penny a kilogram of carbon. This tax would, of course, have a differential impact. Natural gas would be favored relative to coal, or the price of coal under such a taxing scheme would go up approximately 50% ($10 per ton). You can see that the National Coal Association is not wild about this idea, but it is a subject that is now undergoing analysis by the Congressional Budget Office. There are a number of features to it that really do need careful analysis; for example, its impact on our international competitiveness position. I think that these are issues that can be dealt with on the timing of the imposition of the tax.

9.0 REGIONAL CULPRITS: SOURCES OF GREENHOUSE GASES

Dick Watson, Washington State Energy Office
Olympia, Washington

My assigned task is to address the "regional culprits--the sources of greenhouse gases in the Pacific Northwest." I am not very good at following instructions so I am going to stray from my assigned topic in two fairly significant ways. One, I am going to focus in on the State of Washington for the very pragmatic reason that data for that very specific area are available, and I think that the other Pacific Northwest states will be similar in large respects to Washington regarding the impacts of the greenhouse effect and global warming. However, there will be differences in production of greenhouse gases largely related to the dependence of utilities in different states on coal-fired electrical generation.

The second area in which I am going to diverge is to attempt to identify where we may be heading. How do we start thinking about making policy in the context of an issue like this where consequences are far in the future and uncertainty is very high?

Figure 9.1 probably illustrates what you have heard in the other presentations. It shows the projected contributions of various greenhouse gases to global warming, assuming current rates of increases of these gases. As you can see, the most significant contributor to the greenhouse effect is carbon dioxide, with chlorofluorocarbons, methane, nitrous oxide, ozone, and other trace gases contributing to various degrees.

Carbon dioxide is obviously the greenhouse gas that we focus on from an energy standpoint. In this issue of the greenhouse effect, we are dealing with a fundamental, inescapable fact. If you burn any carbon fuel, be it coal, oil, natural gas, or wood (or

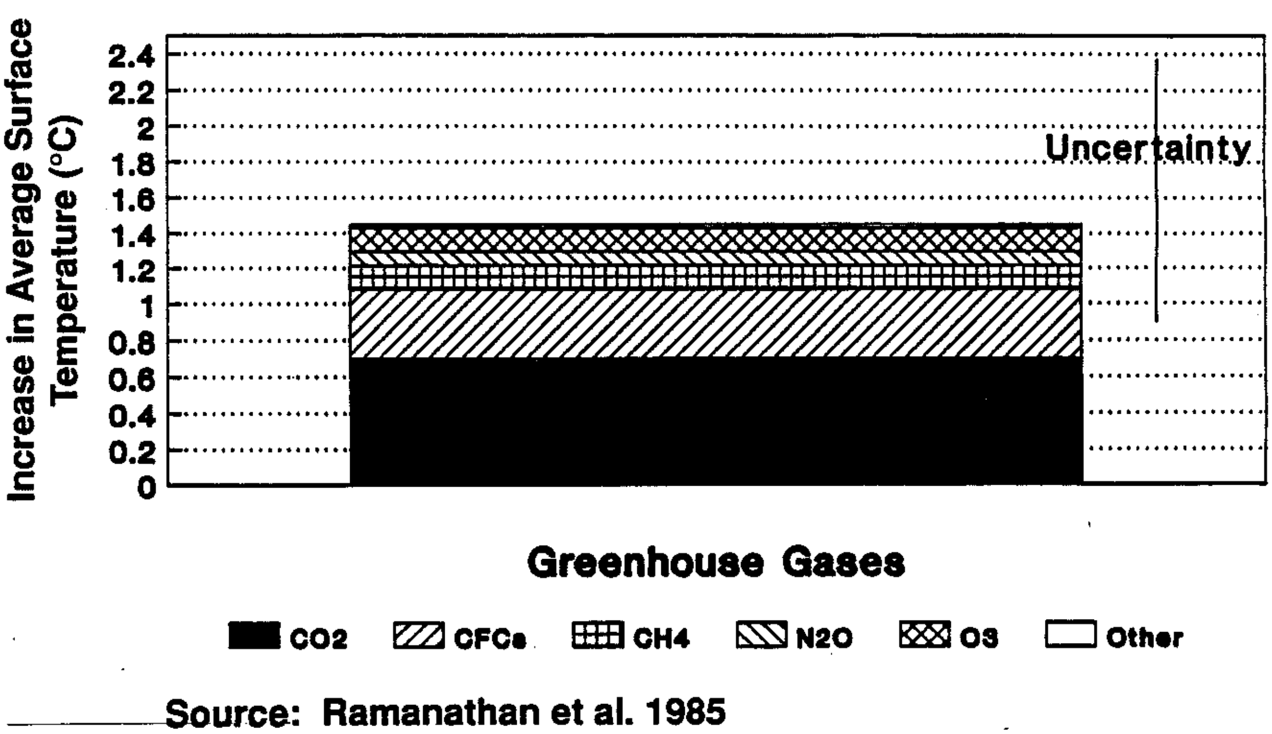

Figure 9.1. Projected Contributions of Greenhouse Gases to Global Warming (year 2030 assuming current rates of increases of gases)

other biomass fuels), you are going to produce carbon dioxide in the process. The other greenhouse gases also have an energy-system relationship. For example, the chlorofluorocarbons are energy-related in that they are the working fluids used in heat pumps and air conditioners. They also are used in manufacture of insulating foams. Ozone is energy-related to the extent that it is produced by a photochemical reaction with hydrocarbons in the smog that we see in our urban areas. Nitrous oxide is energy-related in that it is a product of combustion, and methane has at least some energy-relationship, although most of it is the product of natural anaerobic processes.

The information in Figure 9.2 was shown in earlier presentations. As can be seen from the figure, all fuels are not created equal with respect to the production of carbon dioxide. The production of carbon dioxide in terms of pounds of CO_2/Mbtu of fuel shows coal to be the most significant contributor. Natural gas is a much less significant contributor. Renewable fuels, such as wood, ethanol, and methanol, are also contributors. The methanol shown is produced from wood products rather than from coal or natural gas. All of the fuels produce carbon dioxide when they are burned and wood burning is a very significant source. You can, however, contemplate energy systems where the net production of carbon dioxide over time from these renewable fuels is essentially zero. Rather than burning slash as a waste product, why not use it to produce energy? The carbon dioxide would be released to the atmosphere in any event. Silviculture might produce wood as a fuel over an sustained period, and could be a long-term zero net carbon dioxide producer. However, the figure shows only production of carbon dioxide from combustion; it ignores long-term system effects.

Figure 9.3 takes the next step, as was illustrated generically by Dr. MacDonald earlier. The production of carbon dioxide in electrical generation is shown in pounds of CO_2/kWh for the various technologies and fuels that are involved in electrical generation. A combined-cycle natural-gas turbine produces much less carbon dioxide than a pulverized coal plant, which is more or less the other extreme.

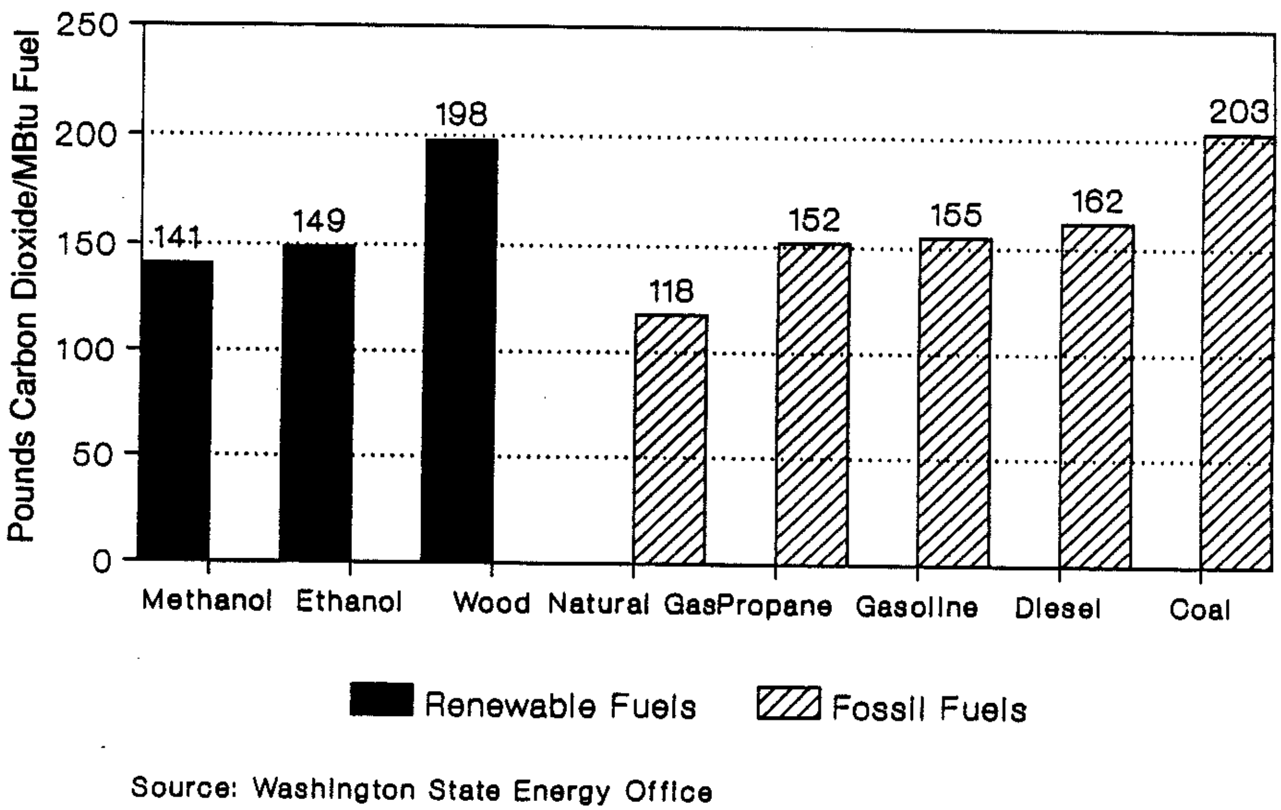

Figure 9.2. Carbon Dioxide Emissions by Fuel Type

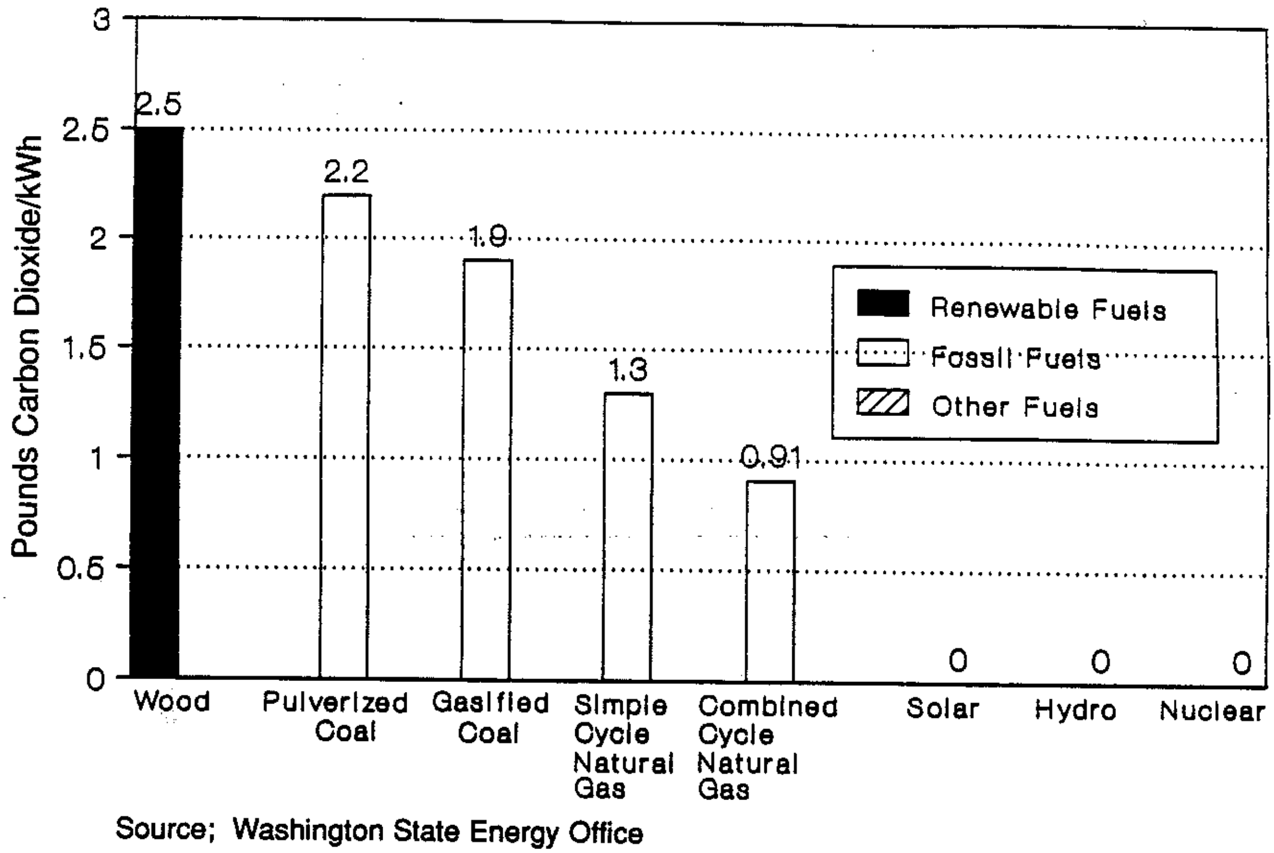

Figure 9.3. Carbon Dioxide Emissions from Electrical Generation

There are, however, other generating technologies, such as solar, hydroelectric, and nuclear, that can produce energy on a zero carbon dioxide basis. I should note here that I am omitting the energy (and the related carbon dioxide releases) needed to build these facilities in the first place.

Figure 9.4 shows emission figures for the State of Washington. Washington is probably much more like the other states in the region than we in the rest of the Pacific Northwest are like the rest of the United States. The figure shows the production of carbon dioxide in millions of tons per year over time in Washington's energy system for three major energy sources: petroleum, natural gas, and coal. We have an added estimate of the contribution of wood to carbon dioxide production here in Washington.

Figure 9.4 also shows a number of events in our energy history, one of which is back in the early 1970s when the Centralia coal plant came on line. The contribution of that power plant to carbon dioxide production causes the total to increase quite significantly. Figure 9.4 also shows that early in the 1970s, when we first got some energy religion and the rate of growth of energy consumption leveled off slightly, the rate of production of carbon dioxide also leveled off. The figure also shows that carbon dioxide production is increasing again in a fairly significant way, largely because of petroleum consumption.

Figure 9.5 is a comparison of Washington to the rest of the United States in terms of sources of carbon dioxide emissions. There are some fairly significant differences, largely because we have a hydroelectric-based electrical supply system and do not use much coal. In the Pacific Northwest, the use of wood probably results in a larger contribution to our supplies of carbon dioxide than it does to the rest of the United States. When we look at the total picture, we are slightly less of a contributor in terms of tons of carbon dioxide per year per person than the

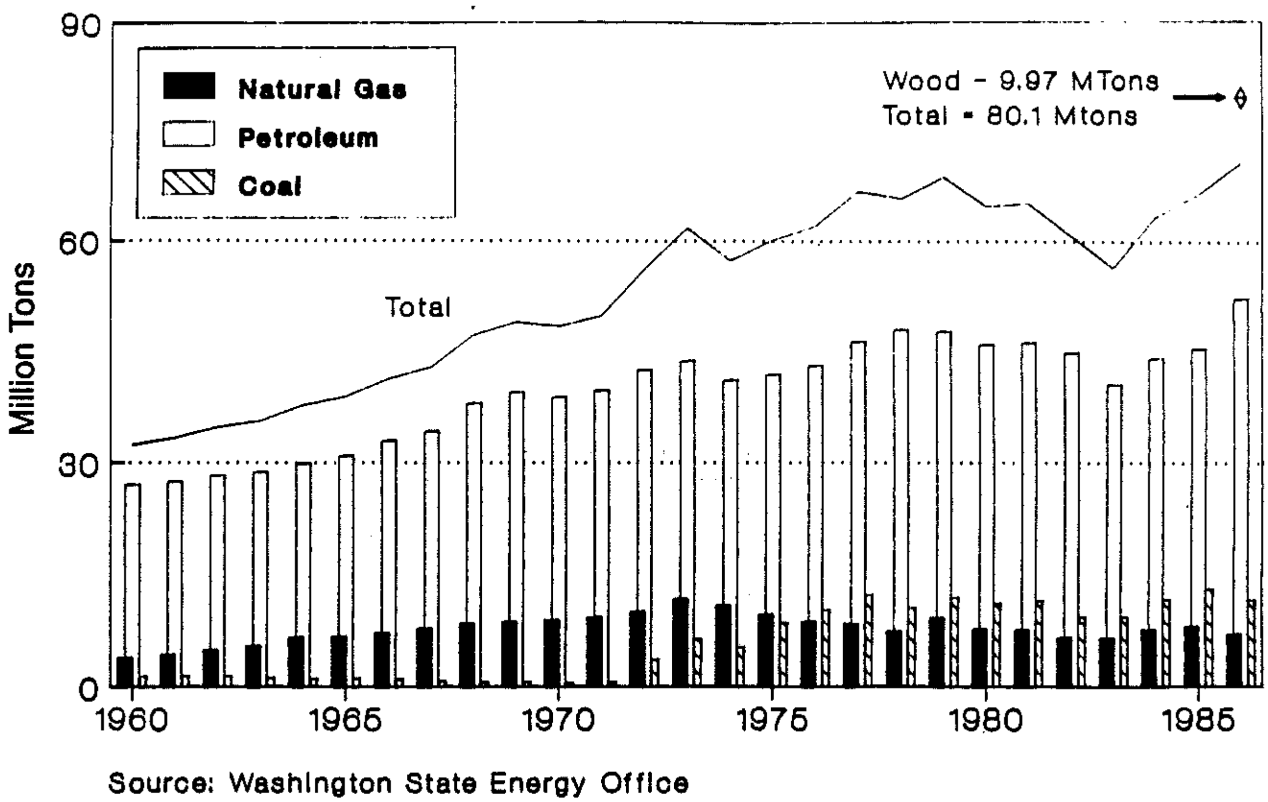

Figure 9.4. Washington State Carbon Dioxide Production by Fuel Type

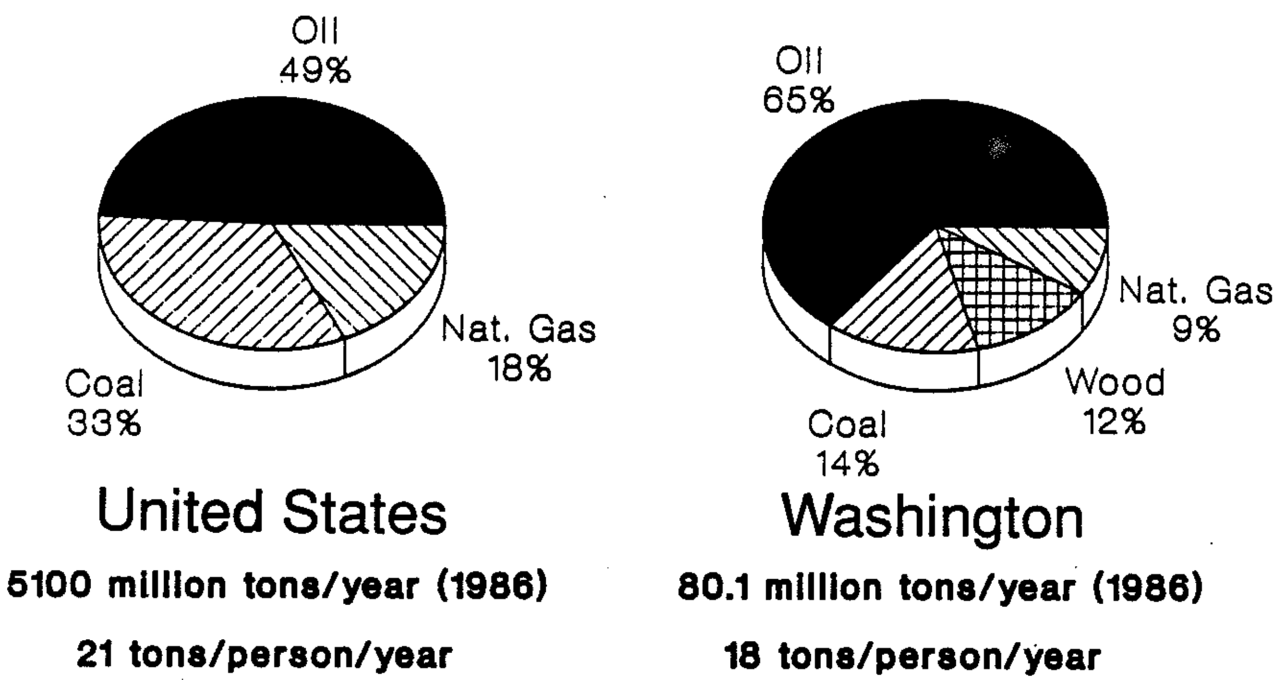

Figure 9.5. National and Washington State Production of Carbon Dioxide by Fuel Type

United States as a whole. This can be attributed largely to our relatively low reliance on coal-fired thermal generation.

Figure 9.6 shows carbon dioxide production according to the sectors of the economy in which energy is used. This figure shows very clearly that in Washington transportation is the major contributor of carbon dioxide, with industrial emissions second, and residential and commercial use in buildings third.

Comparing this information with a national breakdown (Figure 9.7) and again allocating utility energy use to the economic sectors, you again see transportation in Washington, and I suspect in the other Pacific Northwest states as well, to be the largest contributor of carbon dioxide. The figure also has information about the contribution from electric utilities, industry, and commercial buildings.

Figure 9.8 shows how we contributed not only at the national level, but at the global level too. You can see that Washington, in relation to the total North American production of carbon dioxide, is a very small contributor. North America is shown to contribute about 27% of the global production of carbon dioxide. However, our contribution is not so insignificant as to be ignored. Rather, I think we can have some influence on what happens.

The key point in my view is that carbon dioxide from fossil-fuel combustion is a major contributor to projected global warming. Therefore, this is as much an energy policy issue as it is an environmental policy issue. And while we in the Pacific Northwest are a small contributor to the global total, our contribution is not insignificant. This is very clearly not only an international/national issue, but one that requires state and local actions as well.

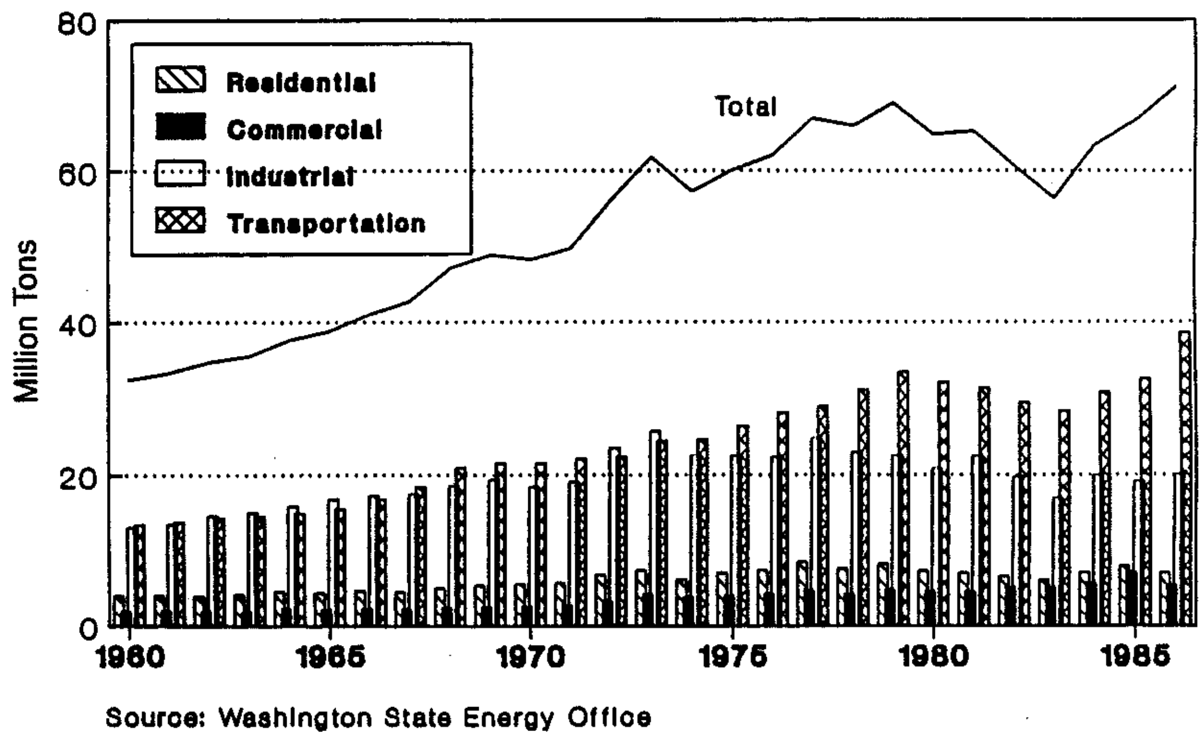

Figure 9.6. Washington State Carbon Dioxide Production by Sector from All Energy Consumption (carbon dioxide from coal based electrical generation allocated by sector)

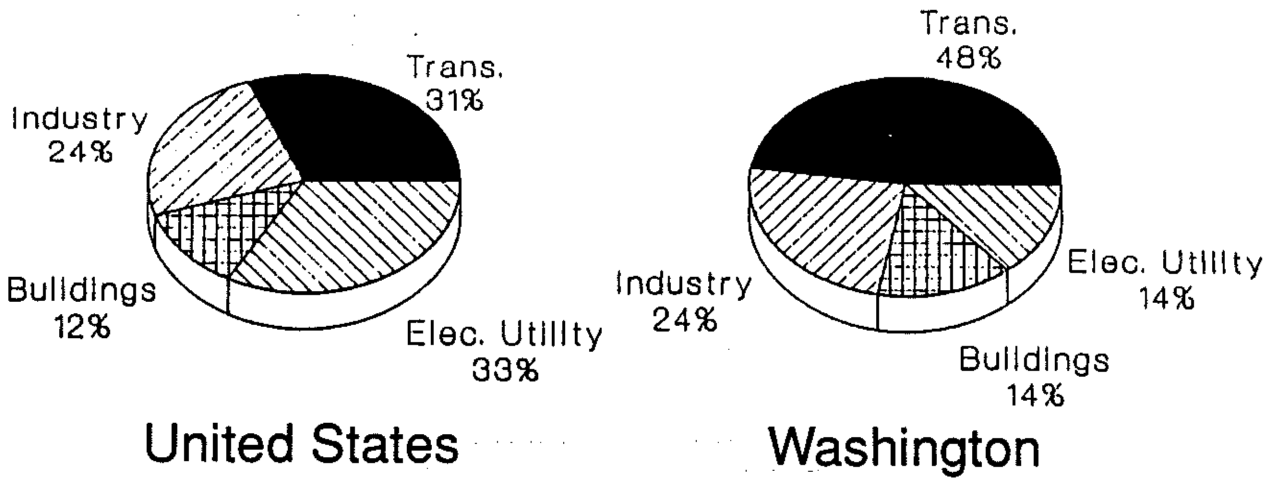

Figure 9.7. National and Washington State Production of Carbon Dioxide by Sector

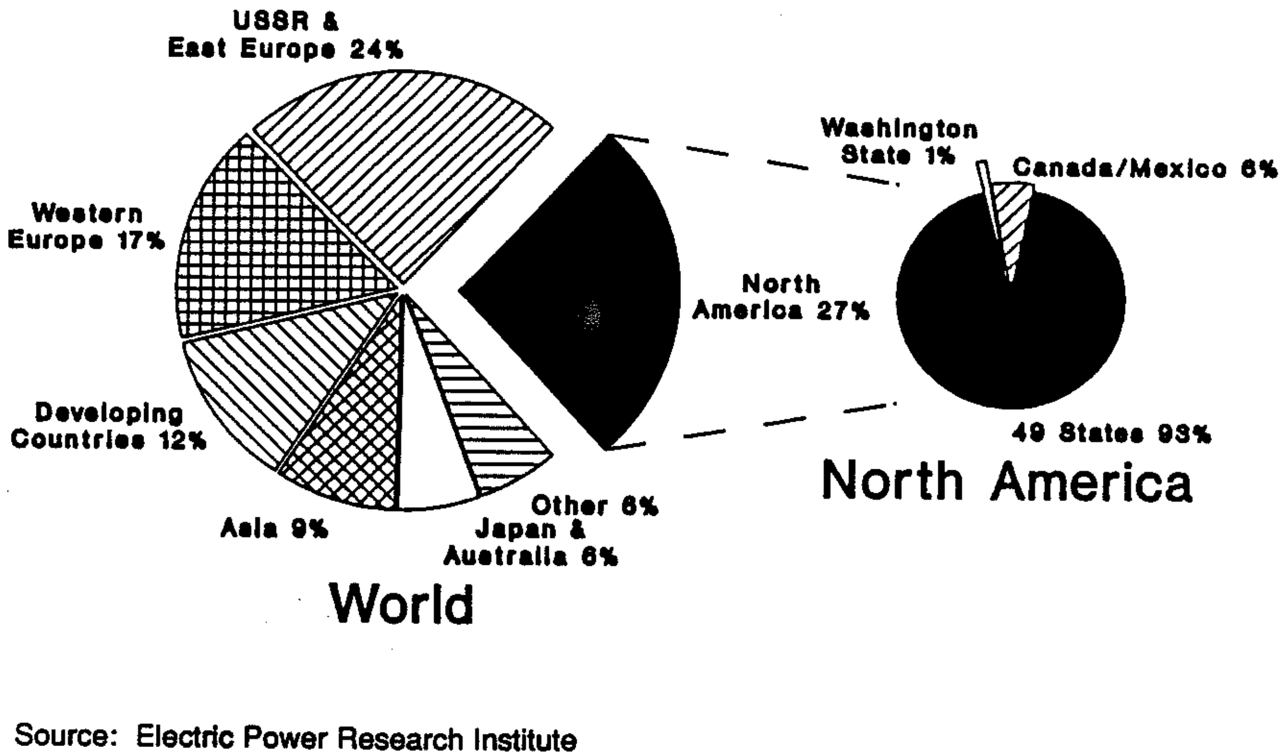

Figure 9.8. Global Distribution of Carbon Dioxide Emissions in 1980

9.1 OPTIONS FOR REDUCING EMISSIONS

Let me turn to the issue that I was not supposed to talk about, but will. What are our options for reducing carbon dioxide? This is kind of a taxonomy of the technical options. We can remove carbon dioxide from exhaust gases, and that is perhaps technologically feasible for a large-fixed source like a coal plant, although it is expensive and it creates its own waste problem that must be dealt with. It is not, however, feasible for mobile sources like automobiles.

A second option is to increase energy efficiency. This is an option that has a significant potential. It is largely an economic issue for us right now and is certainly technically feasible. The third option is the use of alternative fuels--lower carbon fuels, such as natural gas, that can be substituted for higher carbon fuels--and renewables. I, like Dr. MacDonald, am not ready to throw the nuclear option out of the basket of alternatives we can consider. However, I think there are things that we have to do to make nuclear energy a viable option. How much reduction in carbon dioxide might be needed? Well, I do not think anybody knows how much would be needed. However, Figure 9.9 provides a perspective on target figures for carbon dioxide reduction that have been advanced. In looking at a 20% reduction by the year 2000, the critical question is whether that level of reduction is something that is within the realm of reason.[a] Is it something that we can contemplate doing? The figure shows what the level of carbon dioxide production in the State of Washington would have been if we were still using energy at the same energy intensity as we were in 1972. By energy intensity, I mean the amount of energy per dollar of gross state

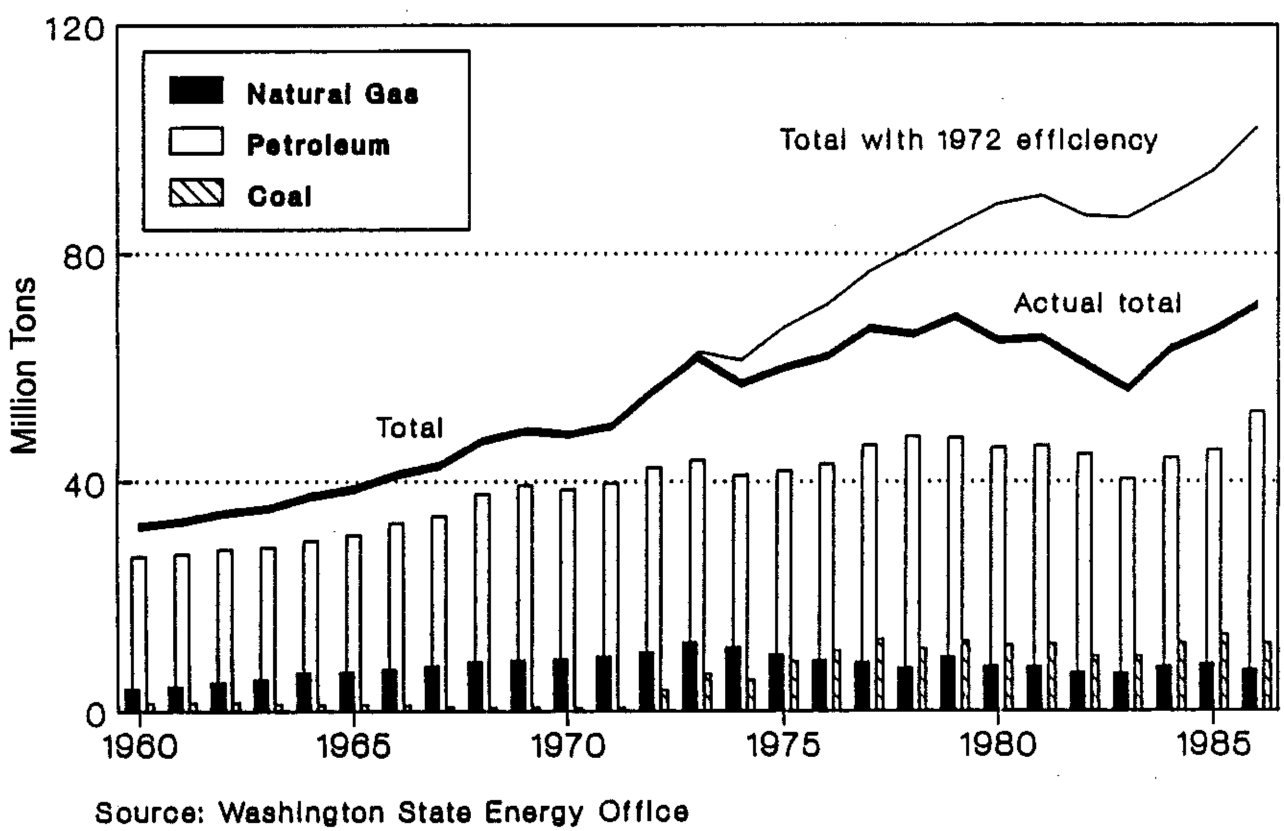

Figure 9.9. Washington State Carbon Dioxide Production by Fuel Type

(a) Editor's note: The Toronto climate conference discussed a goal of 20% reduction by the year 2000. In Congress, the Stafford Bill advocated a 20% reduction in 5 to 10 years and a 50% reduction by the year 2000.

product (that is, dollar of economic activity). The figure shows that--through a combination of changes in the economy and changes in the efficiency of our energy use--we are producing significantly less carbon dioxide (30 million tons per year less) than we would if our level of energy intensity had continued at the level it was in 1972.

This amounts to a 2.2% per year reduction per dollar of gross state product in the production of carbon dioxide. To achieve a target 20% reduction in carbon dioxide by the year 1990 while sustaining a 2% real growth rate in the economy, we would have to have a 4% reduction per year per dollar of gross state product. I think we achieved the 2.2% reduction with a relatively minor effort, quite frankly. It might not seem like it to some of us, but it does not seem to me that a 4% per year reduction is unachievable.

9.2 ENERGY EFFICIENCY IMPROVEMENTS

I believe reducing carbon dioxide significantly requires a two-part strategy. The first part involves the near term and focuses on improving efficiency with some movement toward fuel switching where it makes sense for other environmental reasons. For example, the use of compressed natural gas as a fuel for automobile fleets and truck fleets and for buses in the urban areas. This approach will help solve another environmental issue--the air pollution problem--and reduce carbon dioxide production. And in the longer term, these actions buy us time for the longer-term development of an energy-efficiency foundation--more efficiency improvements, greater technology advances, developing some renewable options, and looking at what it is we have to do make nuclear energy a viable piece of our overall approach.

In Washington, transportation is our major problem. The problem is the cars that are running up and down the freeways, which also are major problem from a variety of other respects that include air quality and congestion. There are a lot of opportunities in the transportation sector for reducing carbon dioxide emissions through improvements in fuel economy, through improvements in the utilization of the transportation system that we have right now, through alternatives like mass transit, and through approaches that might substitute for physical transportation (for example, telecommunications). How much could we really substitute for physically moving people around and how much could that approach contribute to reducing carbon dioxide?

Figure 9.10 shows data on carbon dioxide reduction potential for the transportation sector in Washington. How much carbon dioxide is produced per vehicle mile of travel as a function of the fuel economy of the car? The figure shows where we were back in 1970 and where we think we were as of 1986. The figure also shows where the fuel economy standards should have taken us, and where, as a result of rollback in the fuel economy standards, we will be going. Finally, the figure shows where we could be based on most efficient available designs. These are automobile prototypes that are operating. They are real automobiles and could result in a very significant further reductions in carbon dioxide production.

Transportation system utilization is also critical and is the whole problem of congestion in the Seattle area. Part of the problem is a result of a utilization rate of 1.1 passengers per car. If we were to take that 1.1 passenger per existing car and translate it into 1) a more efficient car and 2) a car with two passengers in it, we would solve two problems. We would get rid of that messy tenth of a passenger and we would take care of more than half the carbon dioxide production. We could make greater use of van pools and buses. Figure 9.11 shows our existing Metro system in the King County area right now, given its current level of utilization. The figure also shows its potential. Obviously, we will not be able to achieve this level of potential, but we can make improvements. We could make greater use of rail transport, especially electrically-driven rail transport. Depending on how you choose to generate the electricity for that rail system, it could be a real winner or not such a winner with respect to carbon dioxide production.

Let me shift to industry now. The following are just a few examples of real energy savings, things that have been done and that we know work. For example, the Frito-Lay Plant in Vancouver, Washington, installed heat recovery equipment. That investment should have a 2-year payback period and will save 117,000 therms of natural gas per year. It

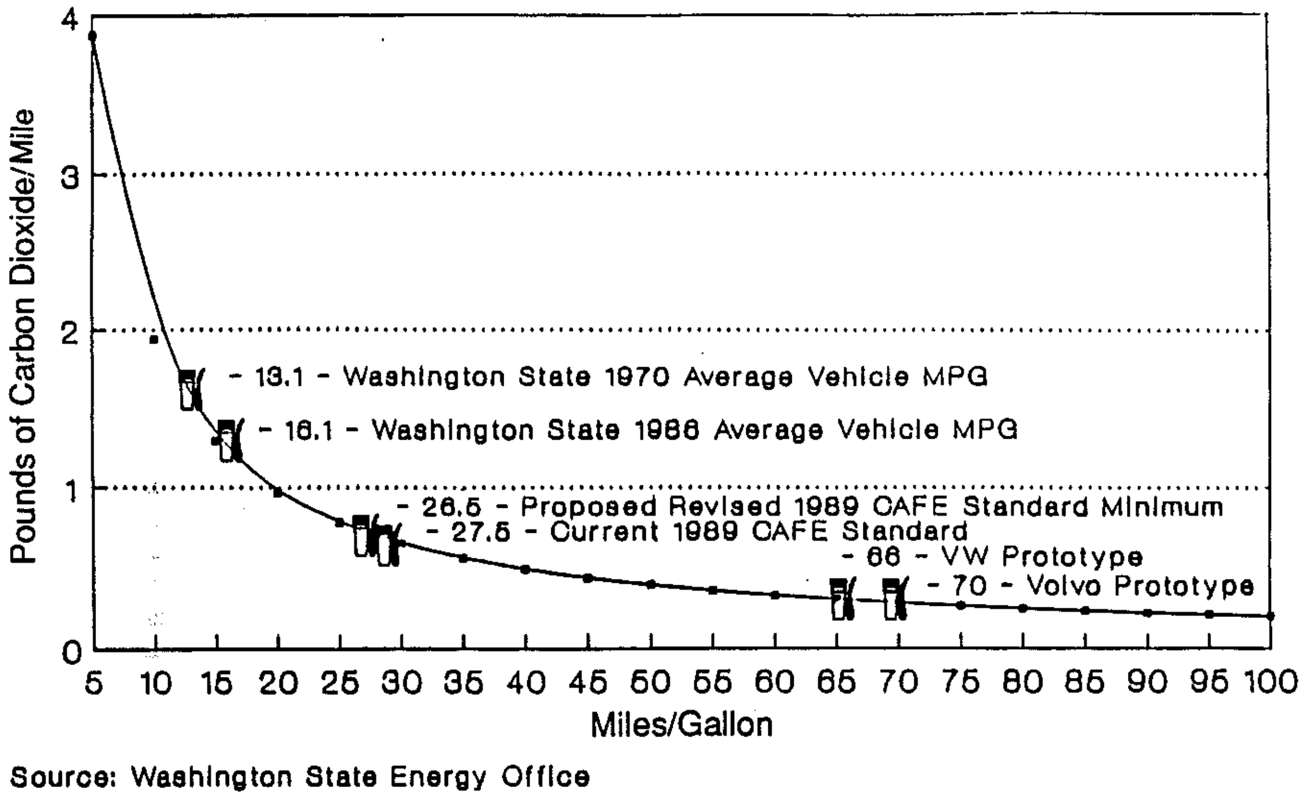

Figure 9.10. Automobile Fuel Economy and Carbon Dioxide Production

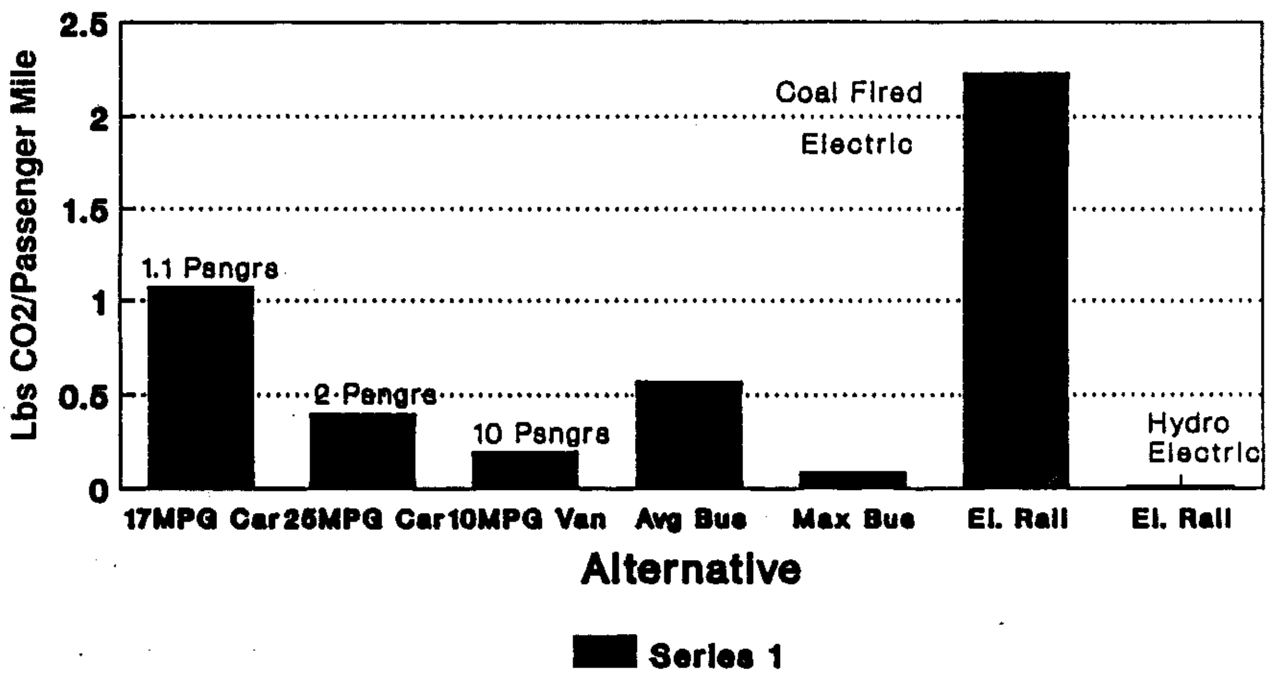

Figure 9.11. Carbon Dioxide Production for Transportation Alternatives

would reduce carbon dioxide production by over a million pounds per year. We can replace a 150-watt incandescent lamp with a 35-watt high pressure sodium lamp. This change would be cost effective and reduce carbon dioxide production by a 1,000 pounds per year, assuming that we are displacing coal-fired generation, which is the limit as we add (under current plans) new generating resources to the our regional mix.

Another example from the commercial sector involves a Skipper's Seafood Restaurant that we worked with in the Bonneville Power Administration's Energy Edge Program. A variety of innovations in that restaurant saved over 74,000 kWh/yr and 3,300 therm of natural gas per year. The investment achieved a 2-year payback and reduced carbon dioxide production by 205,000 pounds per year, again, displacing coal-fired generation.

In Spokane, a small office building built to high levels of efficiency will result in a 44,000 pounds per year reduction in carbon dioxide. In the residential sector, we could install flame-retention burners in oil heated homes. This is something that we are doing on a daily basis, and it could reduce carbon dioxide by over 200,000 pounds per year. Just getting a gas-heated in a home built to the current state code, which unfortunately we are not really doing, could reduce carbon dioxide by 1,600 pounds per year. Building electrically heated homes to the model conservation standards reduce carbon dioxide production by 4,300 pounds per year per home. Today we heard Governor Gardner endorse this as an approach that Washington has to take. I certainly hope that Washington will be successful in doing that, and I hope Oregon joins us.

Figure 9.12 illustrates the importance of conservation in the Power Council's Regional Plan. To develop this information we used the Power Council's planned mix of resources, which includes a lot of conservation and eventually starts moving into different kinds of thermal generation--gas turbines, cogeneration, and ultimately coal-fire generation. Figure 9.12 illustrates for the current resource stack under average hydroelectric conditions, how carbon dioxide production would start increasing in the future. The second line shows, under the current plan, how carbon dioxide would increase if we are not successful in achieving the conservation components of the Regional Plan. There is a significant difference. I have to tell you that, although we can show that conservation can work and be cost effective, it faces a lot of market, institutional, and political barriers, and it is by no means assured that we can in fact achieve this. This, to me, very much illustrates the importance of not only doing the Model Conservation Standards for the residential sector, but improving them for the commercial sectors and also doing retrofit activities in commercial, industrial, and residential sectors as well.

The key point is that improvements in energy efficiency are demonstrated effectively in every sector of our economy. They can pay for themselves in terms of energy cost savings. They can reduce carbon dioxide production, and they can help solve other problems, like our increasing petroleum vulnerability. We are now importing more petroleum than we did in 1974. Energy efficiency improvements can help reduce traffic congestion, improve air quality in our urban areas, and reduce the acid rain.

9.3 ALTERNATIVE FUELS

Alternative fuels--lower carbon fuels, some fuel switching, cogeneration, combined-cycle gas turbines--have been shown to be clearly less carbon-dioxide intensive ways of producing electricity. However, we have to be concerned, probably more than anything else, about the assumption that we are going to get a carbon-dioxide reduction for free. If natural gas becomes a "preferred" fuel from a greenhouse effect standpoint, for example, it is clearly going to have an impact on the price of that fuel.

We have largely turned our back on renewable resources options, and I think that it is an option that we have to look to again. Even when we are being very, very careful about the protection of our environmental values, we still have potential for developing hydropower in the Pacific Northwest. There are other sources of renewable energy that, with some work, can be positive contributors as well.

With respect to nuclear power I think that we have to address three important issues: cost, safety, and waste. And whether you are a supporter or an opponent of nuclear power, the perception is that

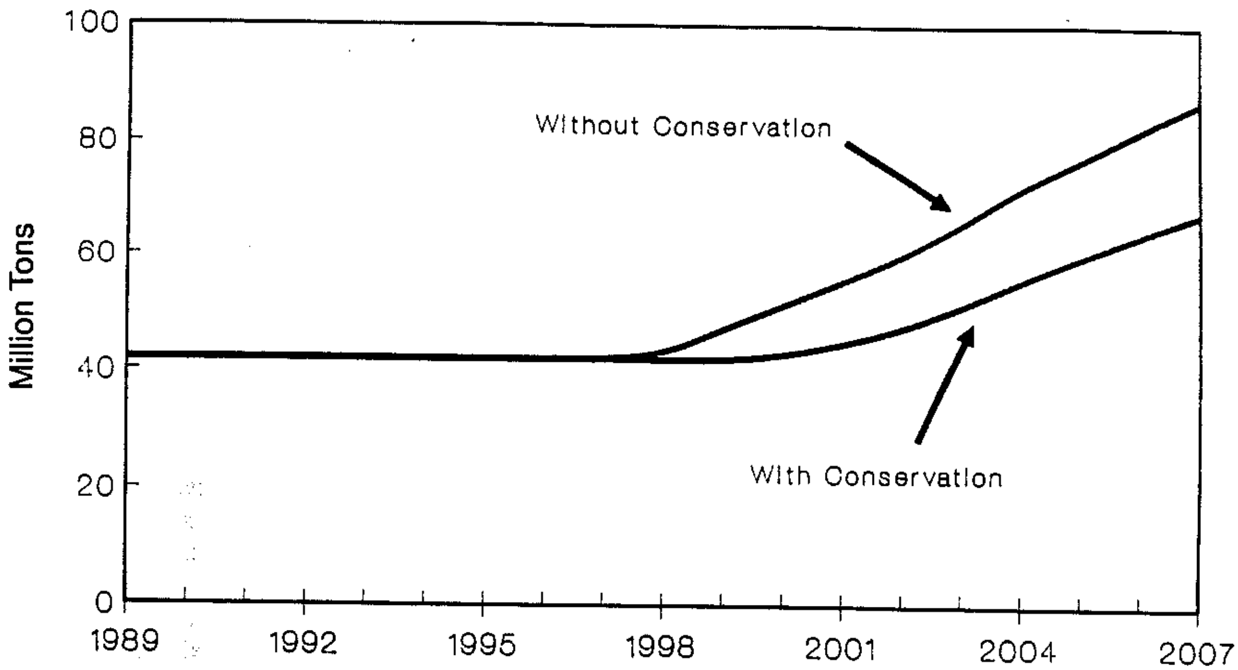

Figure 9.12. Regional Carbon Dioxide Regional Production from Electricity Generation With and Without Conservation

those are problems, and perception is reality. Something is going to have to be done with nuclear energy to make this a realistic part of the options that we have for our long-term future. The concern that I will raise is the potential for draining away resources from the kinds of things we know can work right now, which is energy efficiency.

9.4 A POLICY AGENDA

Very clearly the greenhouse effect is an international problem that is going to require international agreements to solve. And this certainly poses clear problems particularly with respect to the developing nations who are planning on increasing their energy use as a means of improving their economic situation. If we do not get our own house in order, we will not be able to convince developing nations that they ought to alter their energy-use patterns to reduce carbon-dioxide production. In my view, a national energy plan needs to be developed along the line of not only a least-cost framework as pioneered by the Power Council, but perhaps a least-carbon framework as well. And some of the elements might include a carbon tax as Dr. MacDonald spoke about earlier, with efficiency standards moving forward on cars, appliances, and buildings. Research and development will be required to bring some of the renewable resources forward and address the issues that I raised with nuclear power. We also will need to return to some of the programs that we have demonstrated to be effective here in the Pacific Northwest, like the weatherization program.

However, great uncertainty exists with respect to the greenhouse effect. As somebody said, "Our models are too simple and the earth is too complex." You heard this morning about the great degree of uncertainty and the kinds of different directions we might go with respect to global warming. The question I have is, "How do we make a political decision about this issue in the light of that kind of uncertainty and really unknown costs and benefits?"

Figure 9.13 is very complex, but in my mind, it is the most important figure that I have to show you. It demonstrates our action options, beginning with

Action	Outcome: Global Warming Doesn't Occur	Outcome: Global Warming Does Occur
Don't Take Action to Reduce Carbon Dioxide	0 * No Initial Costs * No Benefits	- - - - - - - - - No Initial Costs No Benefits and * Rapid and Significant Global Warming * High Long-Run Costs To Mitigate Impacts
Pursue Efficiency-Some Fuel Switching to Reduce Carbon Dioxide	++ Some Initial Costs But also * Energy Cost Savings * Greater Energy Security * Reduced Traffic Congestion * Improved Air quality * Reduced Acid Rain	+ + + + + + Some Initial Costs But Also * Energy Cost savings * Greater Energy Security * Reduced Congestion * Improved Air Quality * Reduced Acid Rain * Slower, Less Severe Global Warming * Lower Mitigation Costs

Figure 9.13. Decision Options - A Question of Risk

the "do-nothing" option. "Do nothing" implies no action to reduce our carbon-dioxide production, and an "action" option in the near-term pursues an efficiency strategy. Both strategies are evaluated against potential outcomes. The potential outcomes are: 1) global warming might not occur due to unforeseen factors and we might not see the kinds of consequences that have been described today, and 2) global warming would occur. If we choose to do nothing and we do not experience global warming, there are no costs, but no benefits either. If we pursue the energy efficiency option and global warming does not occur, we still achieve all the other benefits described in the figure--energy cost savings, greater energy security, reduced traffic congestion and improved air quality, and reduced acid rain. There are a number of very real benefits that in my mind provide a valid reason for pursuing efficiency even without considering global warming. If global warming does occur, and we have not taken action, then we stand the risk of rapid and significant global warming and high, long-run costs to mitigate the impacts. If, on the other hand, we have pursued an efficiency-base carbon-dioxide reduction strategy, we are still going to have some impacts, but we are going to get ancillary benefits and we will have, to some extent, extended the timing and reduced the associated mitigation costs of global warming. As Governor Gardner said, this looks like a win-win proposition to him. It looks like a win-win proposition to me too. And I hope that we can in fact move in a positive direction along these lines.

10.0 REGIONAL RESEARCH NEEDS

Peter Beedlow, EPA Corvallis Laboratory
Corvallis, Oregon

This afternoon I would like to discuss the EPA Global Climate Change Research Program. This program is relevant because the focus of the national program is regional analysis. While in the past year we have been involved with some specific regional studies, we have not implemented any of these studies in the Pacific Northwest. These regional studies were part of the congressional reports that were discussed earlier, and I just wanted to briefly identify EPA's involvement in preparing the reports to the Congress. This first report, which is entitled *The Potential Effects of Global Climate Change*, deals with the scientific side of things. The second report examines the policy side, and focuses on stabilizing solutions. Both of these reports are in draft form, and they are scheduled to be submitted to the Congress later this year.

10.1 EPA GLOBAL CLIMATE CHANGE PROGRAM

Planning for the EPA Global Climate Change Research Program was initiated at the same time the reports to Congress were initiated following the passage of the Global Climate Act in 1987.

The research is founded on four assumptions. First, the mechanisms of the greenhouse effect are known--trace gases contribute to the insulation effect of the atmosphere causing an increase in temperature. Second, man's activities are contributing to the problem, and we need to derive some policy solutions to help ameliorate the temperature problems that we are anticipating in the future. Third, our ability to quantify those affects is inadequate. As much of the discussion this morning concluded, we simply do not have the capability to analyze the environmental, ecological, and hydrological effects sufficiently to provide input for policy formulation at a regional level. Therefore, our program will attempt to estimate some of those effects. A fourth assumption is that because of the complexity of the issues, we are not actively looking at implementing policy at this point. We are still trying to determine what the problems really are and how we might approach them.

The Global Climate Change Research Program provides a change of direction for the EPA. In the past, the EPA has been "end-of-pipe" oriented. In other words, the EPA focused on particular pollutants from a particular process and their effects and used that information to derive regulations for controlling a particular pollutant. The Global Climate Change Research Program uses a different approach. It is not a traditional point-source, fate-and-effects type of research program. It is a broad scale, multidisciplinary program. Many types of scientist will be needed to address the problem. It is also a multiagency problem. All of the major federal research agencies are involved to one extent or another in the global climate research. Nontraditional from the EPA's viewpoint means that the program is not dose related. You do not expose an organism to "X" levels of a pollutant and get an LD_{50}, for example. We are looking at whole system changes--changes in human systems as well as regional ecosystems.

Everyone realizes that we are involved in a long-term program rather than quick solutions. For example, the basic circulation models that are needed for conducting a regional analysis will not be even available for a number of years. What we are working with now are precursors of the tools that we really need to deal with the problems. The EPA is bracketing a 10-year-plus time frame for this research. Finally, it is an international program in that not only are the developed countries involved in addressing the global problem, but there is also a great deal of cooperation among the federal agencies and the governments and research organizations in other countries.

Federal guidance and coordination of the program, is provided primarily through the Committee on Earth Sciences. This committee has representatives from most of the important government branches dealing with the problem. There are a number of other mechanisms that the EPA is using to coordinate its effort. The Global Climate Research Program has a committee on which the EPA sits. The EPA's primary responsibility on that committee is twofold: 1) answering questions about and formulating policy about emissions, and 2) supporting several particular areas of research, especially in hydrology and ecological effects. Interaction with the academic community in the United States is primarily through the National Academy of Sciences (NAS). The EPA has representatives on their working group and, of course, the NAS Committee is also participating in formulating the International Geosphere-Biosphere Program (IGBP). In addition to that, there are international research agreements that are in process, or that are in some stages actually implemented with other countries--China, the Federal Republic of Germany, and the Soviet Union, for example.

10.2 RESEARCH QUESTIONS

I want to emphasize that the research approach that the EPA is taking is a policy-driven approach, contrary perhaps to the approach taken by the NSF, whose mandate is to conduct basic research to provide a broad support of scientific knowledge. The EPA mandate is policy formulation and, consequently, while we're doing a bit different type of research than we have done in the past, it still needs to be very clearly directed by policy. There are a number of questions that need to answered. What is the likelihood of man-caused changes in the global climate? How likely are we to see these changes in the next 50 years? What will be the change in regional climate and atmospheric chemistry? We need to know what's going to happen on a regional basis before we can evaluate what is going to happen to our fisheries, our ecosystems, and our water resources. What are the associated magnitude and extent of the change? Over what time periods are these changes likely to occur? And, of course, what are the effects on our natural resources? These policy-directed questions really are forming the basis of the planning that is being done.

We fully realize that some problems exist in what we are trying to do. I would like to summarize the scope of our knowledge at this point. Concerning global climate change, there are a number of things we are fairly sure will happen such as surface warming, precipitation increases, and accelerated input of other trace gases. However, effect of the oceans on the earth's climate is still a big question. As some of the speakers eluded to this morning, the oceans can act as a great sink that decreases the rates of change over many years. When we get down to regional issues, we think that there is likely to be stratospheric cooling, sea-ice decreases, warming towards the poles, expansion of arid areas northward, continental warming, and drying. The significance of the impacts in the grain belts of the continents are not well understood. Also, there may be a potential evapotranspiration increase in the higher latitudes.

We can now discuss some of the detailed but important areas that we need to understand to formulate regional policy. We are quite uncertain in a number of these areas, such as how storm patterns are going to change. Changing storm patterns would probably effect regional hydrology in a large way and may also affect a number of other important areas. We cannot tell much about local hydrology. What would happen in the tropics? Everyone in the area of global climate change studying these issues has recognized the importance of the tropical forests and tropical zones in general in affecting the global climate; we do not know a lot about what will happen in such specific areas. What will be the transient responses? How fast are things going to happen? We do not have answers to these questions either. What kinds of changes will we see in the major ocean circulation patterns? Again, answers to the questions about the oceans are quite uncertain. Changes in oceans will affect our marine fisheries and our freshwater fisheries. Regional climates will also change, particularly in the coastal areas. A good example is the San Francisco summer climate as was discussed earlier today. Of course, it will affect vegetation, and the variability of the seasons will likely change, but we are not sure exactly what changes will occur.

As you can see, we have a lot of questions. We believe, however, that the impacts are likely to be regional, and they are most likely to change dramatically from region to region. What is going to happen in the Grain Belt may be significantly different that what happens in the Pacific Northwest. We recognize that regional analyses are going to be necessary and to some extent each of the regions is going to have to be treated as a separate case--particularly in developing local policy.

An issue such as the total amount of greenhouse gas resulting from biological sources is a really big unknown and likely to be very different from region to region. I do not know how many people are aware of the concerns that exist for the permafrost layer under most tundra areas. A rapid warming in the polar areas will turn these into bogs, which happen to be rich in methane. There is concern that these tundra areas will be much greater sources of methane if they turn into bogs. Other unknowns include local problems with sea level elevations and effects on economic development, agricultural productivity, and biodiversity.

Biodiversity is becoming more and more of an issue not only publicly but within the federal agencies. The questions about loss and extinction of species has been around for some time, but have only recently come to light as federal research issues related to climate change. If global climate change were to cause loss of species diversity, will it also cause ecosystems to become unstable? And of course the other questions are related to loss of sources of pharmaceuticals, and other benefits that can be gained from a particular species. We do not know right now for many particular species.

10.3 GOALS OF THE EPA PROGRAM AND RESEARCH

The goal of the EPA program is provide policy structure. The idea is to evaluate the extent and likelihood of environmental changes associated with changes in the climate system and assess regional ecological changes, including hydrology and the environment as a whole. The program will assess the global and regional atmospheres, as well as the anthropogenic and biogenic contributions to the atmosphere causing the climate change and the response of the natural systems and the managed systems in those areas.

There are several different areas of research within the EPA plan, with corresponding broad objectives. The first area is to evaluate the fluxes of greenhouse gases into the atmosphere and the feedbacks from climate change that may affect the rates of those fluxes. We need to derive regional climate scenarios so that we can do regional analyses and then assess emissions management technologies. This is an important component particularly with respect to anthropogenic emissions.

For the atmospheric sciences, the overall thrust will be to derive the means to develop a climate effects model. We will examine how to go from today's very large grid scales down to something that we can use, and also to incorporate the chemical dynamics that are likely to be produced from the emissions work. However, neither the emissions nor the atmospheric sciences areas are the primary thrust of the EPA program.

Our primary emphasis and basic mandate has been the environmental effects. Other agencies are also looking at the physics involved with circulation models, and the chemistry problems associated with emissions, so we are supporting those activities. We intend to look at the hydrological and ecological effects on a regional basis, changing our emphasis from our typical small-site research to research on very large areas. As an example, we might address what might happen to the intermountain deserts. Our research will support periodic assessments over the next decade in air quality, water quality, forest growth, and sea level effects. We will address how our forests and the timber industry associated with the forest will be affected by the climate change. For example, how will our agricultural regions be affected? Will we be growing corn in Saskatchewan instead of Iowa? How will the agricultural productivity be affected; will we (still) be able to feed the world?

There are three major areas of global research in which EPA research relates to the research being undertaken by other agencies in the government. The first is biogeochemical dynamics (bioemissions sources and sinks of trace gases), and how these are both affected by and affect the earth's ecosystems. The second is physical climate and hydrological systems, including the atmosphere and hydrologic modeling. The third area is ecosystem dynamics in a broad context--not only ecosystems in terms of national parks but the entire ecosystems, agroecosystems, forest-managed ecosystems, and other broad areas.

These three major areas of global research are then broken down into three major questions:

1. Are they initiators of change?

2. How do they respond to climate change?

3. What is our capability of quantifying and predicting this change?

As I said before, the primary emphasis is in the ecosystem dynamics area and supporting other areas.

10.4 SCHEDULE FOR RESEARCH

This is the first year that funding for the EPA Global Climate Change Research Program has been in place. We have funding to establish research plans this year, but the real research will be initiated in FY 1990, and our level-of-effort will increase through the next three years.

Let me give you some idea of where we see ourselves going in the next 5 years and some of the issues that we are going to be addressing. Last year and this year, we are responding to congressional questions, writing the reports to Congress, and developing a research plan that will serve as an umbrella under which the EPA can implement specific research areas. This plan is in draft form right now. It will be reviewed by the EPA Science Advisory Board at the end of this month. After that review, it should be available to the public.

The plan will focus on issues related to the Global Climate Protection Act. We will perform particular scientific assessments and then implement research in the areas discussed below. The first area involves emission factors--the rates of trace gas emissions and particularly what we need to do to incorporate the flux rates into our existing models. We will try to develop some preliminary scenarios that can be used to plan our assessment and research methods down the road. We will take an initial look at the ecological sensitivity of regions. This effort relates to the Pacific Northwest issue in that this year we initiated a piece of research to broadly look at the climate sensitivity of major regions in the United States. After we assess climate sensitivity, the intent will be to initiate research in the most sensitive regions first.

I am not in a position to say which regions will be found most sensitive, but we will most likely begin looking at two to three regions within the next couple of years in a more intensive way. Since this is a startup year, our current investment is very minor. Planning dollars--about $2.5 million in the ecosystem dynamics areas--are being spent in both biogeochemical and the physical-climate and hydrological systems. We are very optimistic of significantly increasing this effort in the following years, starting in FY 1990.

10.5 CONCLUSIONS

To conclude, I want to revisit the subject of impacts to the Pacific Northwest. I want to reiterate that the Northwest, in comparison with other regions of the country, is in a unique situation. It seems that no matter what happens, if we get into any kind of climate change, it is going to affect the Pacific Northwest in some way because of our rather diverse natural resource economic base. Agriculture will be affected, especially the irrigated agriculture on the east side of the Cascade Mountains, by anything that affects the flow rates in the Columbia River. Of course, electric power generation will be affected, not only hydrogeneration, but thermally-generated power. Forest production, fisheries, and sea-level rise are also important issues that must be considered. I think that if you were to compare the Pacific Northwest with other regions around the country, you would find that we have a vested interest in understanding climate change to the best of our ability and in trying to implement policies specific to the Pacific Northwest that will help us in the long run.

11.0 THE ROLE OF ENERGY EFFICIENCY

Ralph Cavanagh, Natural Resources Defense Council
San Francisco, California

Today I am supposed to talk about the role of energy efficiency, and in a shattering break with tradition, I am going to do precisely that. However, I want to do it in a way that does not repeat what has already been said in this symposium. I think I can establish a contrast by noting at the outset that, according to Peter Beedlow, the Federal Government is not yet ready to provide what he called "input for policy makers at a regional level" concerning global warming. And boy is he ever right, as I'll explain in a moment. The Natural Resources Defense Council operates under no such disabilities, however. I am more than delighted to provide some input for policy makers at a regional level, and as I see a number of them here, I am certainly not going to waste the opportunity.

First, however, two acknowledgments are in order. One might think based on this overflow crowd that global warming has been high on the agenda of regional energy policy makers for quite awhile now. In fact, as many of you know, that is not the case. We are here today in large measure because of the passion and commitment of one Power Council member, Ted Hallock. I would like to acknowledge him at the beginning of my remarks today, and note to him and to his colleagues the appreciation that many of us feel for his efforts in that regard.

I would also like to say just a word about the speaker who follows me, Michael Totten. As many of you noted when you received the program for this event, the fifth speaker was simply described as a representative of the Federal Government who would talk about federal global warming initiatives. I was really looking forward to that presentation because I had planned to denounce at length some recent outrages in federal policy on global warming, and I was grateful to the Power Council for providing me with a punching bag who would have to follow me on the agenda and who would presumably have no recourse but to confess error publicly before all of you. Instead, the Power Council delivers Michael Totten to me. More than any other employee of the Federal Government at any level of pay, Michael Totten can take credit for what little good as come out of the Federal Government in the last decade in terms of energy efficiency policy. So let me just emphasize to all of you, that to the extent that I might say a word or two today that is unkind about the Federal Government, I am not talking about Michael Totten.

11.1 EFFICIENCY AND CONSERVATION: BETTER SERVICE, NOT FREEZING IN THE DARK

I think that it is necessary at the outset to say just a word about what I mean when I talk about the role of energy efficiency and conservation. And I was led to that conclusion by a couple of errant sentences in an otherwise really wonderful talk by Michael Scheslinger this morning. But even as Michael Totten and I have much to learn from Michael Scheslinger about climate policy, I hope he will perhaps grant us the right to suggest a modification or two on his treatment of energy conservation and energy efficiency. One of his remarks, by way of characterizing this resource, was to say, "We are all for conservation, but conservation is something you want somebody else to do, not yourself." That is a view of conservation that certainly had a wide currency in the 1970s when everyone understood conservation as freezing in the dark and appearing on national television in a cardigan sweater. However, this region has done perhaps as much as any in the world to reeducate all of us that conservation is not synonymous with sacrifice. Conservation now is a word that means getting more work out of less energy. The Power Council has understood this concept as well as anybody on earth--that nobody places any value on energy consumption for its own sake. None of us have any use for kilowatt hours or therms or barrels of oil except in terms of the services they provide.

When, for example, Michael Scheslinger said that the Third World would like to have the same per capita energy consumption that we presently enjoy, he could not have meant that, because, again, I do not know anyone in the Third World or in any world who enjoys energy consumption. What people enjoy are the services that the various energy forms provide. What the Power Council's work eloquently shows is that level-of-service and quality-of-service are largely independent of the amount of energy consumed. And that is a very critical point in understanding the really quite extraordinary role that energy conservation can play in dealing with this dilemma that you have been informed about today.

What we can draw from the diverse and useful set of presentations given this morning and this afternoon is that global warming, with all of its uncertainties, is one more addition to a very long list of reasons to support energy-efficiency measures. It is one more reason to mourn our lack of progress. It is our lack of progress that I am going to address principally today. Generally I accentuate the positive in my speeches, and I constantly use the Pacific Northwest region as a model for energy conservation awareness.

What I want to address today is how we are falling short and what we need to do about it. Now, let me just review a couple of discouraging trends at the outset, in coming to grips with why I think we need a greater sense of urgency, both in this region and in others.

There was a period from 1973 to 1986 that might called, in some sense, a first golden age of energy conservation. During that period, conservation was by far our largest, most successful, and most inexpensive energy resource. It did all of the things the other speakers have talked about today. Between 1973 and 1986, we increased gross national product in this country by more than 35%; yet, our energy consumption did not increase at all. More to the point for today's purposes, our carbon dioxide emissions did not increase at all. In fact, they dropped marginally between 1973 and 1986. That means that you do not need a World War or a Great Depression in order to reduce carbon dioxide emissions.

However, the sad fact is that since 1986 things have changed. In 1987, robust growth in energy consumption actually increased carbon dioxide levels above 1973 levels, so we lost our previous gain in emissions for the United States as a nation. Growth in energy consumption continued very rapidly through 1988. I do not have the full year's figures yet, but I did perform a comparison, for example, for the first 8 months of 1988, compared with the first 8 months of 1986, for one of the critical carbon dioxide sources, namely coal. Coal consumption in this country increased 10% during the first 8 months of 1988, compared with the same period in 1986. This is just a little flash indicator that energy-consumption growth is resuming. I would not place all of the fault for the resurgence of energy consumption in this country on lower prices; although, that is certainly a significant contributor. I place part of the fault on policy makers--on our abdication of what in the 1970s began to be a serious national and regional commitment to make energy efficiency happen.

11.2 RETREAT IN FEDERAL POLICY

You have already heard about some of the problems at the national level. You have heard about the rollback in automobile fuel-efficiency standards that happened for the 1989 model year. Incidently, that was the fourth year in a row that federal fuel-efficiency standards had been rolled back. The standards themselves only go up to 27.5 miles per gallon, though, and we clearly have a long way to go before we can even approach the higher levels of the chart that Dick Watson presented. At the end of 1988, the Federal Government proposed efficiency standards for refrigerators, freezers, and television sets that would have pushed the energy efficiencies of those appliances to the limit of the technologies currently available. If the Federal Government had implemented those standards, we would have been in a position to save a 1.5 billion barrels equivalent of oil and gas over the lifetime of the appliances covered by the standards, along with some 20,000 peak megawatts of power plants (for example, 20 large nuclear plants). That was what the Federal Government could have done at the end of last year when it issued national appliance standards just on refrigerators, freezers, and television sets, which are the core elements of every American's life. Instead, in the proposed standards, they essentially ruled out two-thirds of the available savings, left open the possibility of capturing the remaining one-third, and indicated, at least in the draft rule, a strong preference for no action at all. Now we do not have to take that result as fate, any more than we have to take the rollback of the automobile-efficiency standards as fate.

Obviously, the work is not yet done on the appliance standards; we still have a chance to reverse the government position. For the automobile-efficiency standards, the rollback for 1989 is being litigated in federal court by the Natural Resources Defense Council. For 1990, the rollback has not yet occurred, and there is still time to prevent it. And there is still time to help Michael Totten and Claudine Schneider enact the legislation he will be telling you about in a moment; the legislation will begin again the progress toward better fuel-efficiency standards.

Incidently, a third horror that recently emerged from the Federal Government was a remarkable reversal of policy by a group called the Council on Environmental Quality (CEQ), which is in charge of administering and overseeing the National Environmental Policy Act. By the end of 1988, the CEQ noticed that there was something called the greenhouse effect, a remarkable and welcome reversal of an earlier attitude. They proposed to issue some guidance to federal agencies about evaluating the impact of major new initiatives on emissions of greenhouse gases. What happened toward the end of the Reagan administration was that the CEQ was directed by other forces within the administration to withdraw that guidance. It does not now exist, and there is no formal linkage between the administration of the National Environmental Policy Act and the issues that we have been discussing today. This is another reason to feel discouraged, but I refuse to leave you feeling discouraged, because the good news--and you have heard it over and over again in different forms today--is that energy efficiency can make an enormous difference in terms of what happens to carbon dioxide emissions. If we simply find ways to make effective use of technologies that we already have, we can make a difference on this problem. As every speaker has told you, the greenhouse effect is only one of a number of good reasons for increasing energy efficiency substantially.

11.3 PACIFIC NORTHWEST REGIONAL POLICY

I suggest that this region's experience has some unique things to tell us and some unique promise in terms of giving the rest of the country and the world guidance in dealing with this issue. You have seen innumerable viewgraphs, today. I hope you are not suffering unduly from a 20 minute break in them. Viewgraph after viewgraph has shown you something that any Pacific Northwest audience ought to be very familiar with. It is the old trend lines. Other speakers have shown you what will happen, if energy growth continues its current trend for 10, 20, 30, 50, and 100 years--the lines go shooting up toward infinity at constant or increasing rates. We have all seen graphs like that before. Those were the same kind of graphs that were used to justify the extraordinary thermal power plant construction program that occurred this region in the late 1970s and early 1980s. We all know what happened to those graphs. The Power Council exposed the fallacy of those graphs with its own independent analyses and showed that an energy consumption trend was not destiny. It was something we had control over. It was something we could influence. It was something we could make choices about. We can choose a different future than the future you keep seeing displayed up there on that screen with all of those lines shooting up toward infinity and with all the terrible attendant environmental and economic implications.

We can do more in this region than just get behind Michael Totten and Claudine Schneider and getting their legislation enacted, although that is an important part of what we all should be doing. I want to look just at regional policy, and I want very briefly suggest to you a few things that we could do, not in 50 years, not in 30 years, but right now, this year, to start making a difference on energy-efficiency policy for this region.

11.4 MODEL CONSERVATION STANDARDS

Yesterday evening, I sat behind Tom Trulove, Ted Bottiger, and Norma Paulus in a hearing before the House of Representatives in Olympia and once more heard the debate over whether we should enact the Power Council's Model Conservation Standards as a code in Washington State. It was both encouraging in the sense of all of the good things that were said and the eloquent way that they were said, and discouraging in the sense that we are more than 8 years from the enactment of federal legislation that requires the adoption of Model Conservation Standards throughout the region. More than 5 years after the Power Council published the first Model Conservation Standards for residential buildings, less than one-fourth of all new all-electric single-family houses in this region are being built to the Power Council's standards. We are going to enact the Model Conservation Standards in Washington this year. We are going to do it in large measure because of the extraordinary devotion and effort of the people from the Power Council. I thank them for their efforts, but I also want to give them a challenge. They can benefit from a little friendly advice and pressure from all of us. You have not heard anything about the problem of noncompliance with the Power Council's Commercial Building Standards. The reason that you have not heard anything about that is because, in relative terms, the Power Council has stone-age Commercial Building Standards. The members present here today were not principally responsible, but they can do something about it.

11.5 COMMERCIAL BUILDING STANDARDS

The commercial sector is the most rapid growing sector in the region in terms of energy consumption; however, the Power Council still uses the industry consensus standards that were adopted in 1980. Essentially the process by which industry consensus standards are adopted is one in which the folks who build the buildings, the folks who design them, and the folks who finance them get together with a token environmentalist, like me, and the lowest common denominator for standards gets adopted. The result of that process (if you can call it a process) are the Power Council's Commercial Building Standards. The Power Council will have an opportunity to do a whole lot better when it enters rulemaking on that issue, as I certainly hope it will a little later this spring. Last week the DOE adopted standards for its own nonresidential buildings that are significantly tougher than the current Pacific Northwest version. We need new Commercial Building Standards.

11.6 UTILITY REGULATORY REFORM

There is a third thing that we need. We need it immediately, and we need it in all four states in the Pacific Northwest. And I think that I am now going to say something that I hope will surprise and really shock many of you. In every single state in this region, because of the way the regulatory system is set up, energy conservation investment by utilities is inherently unprofitable. If a utility successfully promotes energy conservation, its profits are automatically reduced. Nobody ever made a conscious decision to make the system work that way. It is a crazy, unintended consequence of the way that rates are set.

Now you can imagine what this does to the incentive for the utilities to get serious about conservation. It will not prevent executives of the Pacific Northwest utilities from rising before you and singing the praises of energy conservation. They will do that, and many of them are quite sincere. We need a system that decouples a utility's profit from the number of kilowatt hours it sells, or the number of therms it sells. We need to change the system so that a utility's profits do not rise and fall in lock step with the number of energy units it persuades people to buy. If we have learned nothing else, we have learned that the quality of service does not depend on the number of kilowatt hours and the number of therms. Why on earth do we want to reward our utility managers based on their sales volumes? The correction is straightforward and something we can do quickly. I call upon the Power Council, as the National Resources Defense Council has before, to convene a four-state meeting of representatives from Washington, Oregon, Idaho, and Montana to explore ways to remove this major regulatory obstacle to getting conservation practices implemented effectively in this region.

11.7 ACCOUNTING FOR COSTS IN PLANNING

There are two other items on my five-point remedial agenda of things we can do now. The fourth is to begin accommodating the costs of reducing carbon dioxide emissions in our estimates of what the different resources that we are considering are going to cost us. Right now, carbon dioxide is the one major pollutant in this country that is not regulated at all. There are no limitations on emissions of carbon dioxide. There are no fees; there are no charges. I ask all of you, as people who are thinking about responsible and prudent utility policies, is it sensible to assume that we will not do anything about that for the next 20 years? Is it sensible to assume that carbon dioxide releases will continue to be free to any industrial entity that wants to do it indefinitely. Yet electricity planners continue to assume that no cost is associated with the emissions of carbon dioxide, and by that failure to impute or imagine or to assign any cost, they are effectively forever. The Power Council should stop that practice. For example, when evaluating the cost of new coal-fired power plants, gas turbines, or anything that emits carbon dioxide, the Power Council should be looking ahead to the likely cost of carbon dioxide controls as imposed by future regulators. I am not asking you here to do anything that is any sense decoupled from actual costs that ratepayers will see. I am asking you to anticipate those costs and accommodate them up front, so that we are realistically evaluating our investments in long-lived resources and ensuring that we are not unpleasantly surprised by the costs of coping with greenhouse-gas emissions.

11.8 RESOURCE ACQUISITION STRATEGY

This issue really ties into the last thing that I think we need to do, which involves a recent BPA document entitled *Acquisition Process for Generating Resources*. This document is BPA's proposed blueprint for how the region is going to acquire new electricity-generating capacity when the present surpluses disappear.

In looking closely at that title, it may occur to some of you, as it occurred to me,that there is something missing. There is something missing from most of the resource acquisition processes that are now used to select new sources of power in this country. Earlier, you heard references to the auctions that are increasingly being used by utilities all over the country to get new power supplies. Those auctions are appearing in this region. BPA wants to use them, and the Washington Utilities and Transportation Commission is developing rules for them. It is absolutely critical, as we implement these auctions, and create these new mechanisms for acquiring power supplies, that conservation and generators compete on equal terms for the ratepayers' dollars. It is essential that we reject resource acquisition processes that pay generators only. We also need to ensure that, in setting up those rules, we include the costs of dealing with carbon dioxide emissions and treat them up front as part of what is relevant in evaluation--whether we opt for conservation or whether we opt for generators. We need to determine what is the best buy for the ratepayer.

11.9 CONCLUSIONS

You will have a chance in the next year to help make all of this happen. The BPA resource acquisition process will be finalized. Washington State will establish bidding rules under the guidance of Sharon Nelson, Dick Casad, Bud Pardini, and their Staff Director, Steve Aos. I am confident that the Washington State rules are going to set a national example for how to make this equal competition between conservation and generation work. I am hopeful that we can get the same kind of leadership out of BPA, and if we do, then the rest of the region will follow.

I am going to close on an optimistic note, with a couple of sentences about conservation that none of you will find remarkable until I reveal the source. This statement appeared in an Op-Ed piece that was published throughout the region about two weeks ago:

> "Well chosen conservation measures are the region's best way to delay the day when expensive new sources of electricity will have to be acquired. Alternatives to conservation exist. Any may be chosen to meet some of our electricity needs, but none are as attractive as conservation. Conservation is the best, lowest cost energy resource at our disposal today. And like a perennial cash crop, conservation produces benefits for years after the seed is planted. Today's wise investment in conservation will let the Northwest shape its energy future."

The author is not me. It is not Dick Watson. The author is Jim Jura, Administrator of the BPA. His agency's progress on this issue illustrates why I am confident that we will not simply wait for global warming to happen to us, but that we will get out and do something about restraining it.

12.0 THE GLOBAL WARMING PREVENTION ACT (HR 1078)

Michael Totten
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12.1 THE EARTH HAS A FEVER

When sick and bed-ridden, a person seeks a remedy rather than ignoring the symptoms. Mother Earth has a fever, and if we ignore her symptoms, we imperil ourselves. It would be easy to become overwhelmed by this new problem, given the long list of other formidable global and national problems:

- famine and poverty afflicting more people than any other time in history
- stratospheric ozone destruction
- tropical deforestation of an area the size of Pennsylvania every year
- an extinction spasm in the wake of forest loss, with species disappearing at a rate not experienced since the extinction of the dinosaurs 60 million years ago
- population the size of the United States being added every 36 months--over 90% occurring in developing countries--edging more and more of these countries over their environment's sustainable carrying capacity
- massive debt threatening the economic productivity and standard of living of the United States and many other countries.

The seeming intractability of these problems has led many people to assume, and advocate, that humanity will have to adapt as the greenhouse fever reaches crisis proportions.

12.2 COSTS AND LOSSES TO THE UNITED STATES IF NO ACTION IS TAKEN

According to the EPA, the following costs and losses to the United States are likely to occur if no action is taken:

- Over $100 billion will be needed to protect coastal areas.
- Seven thousand miles of shoreline will be destroyed, despite this costly protection.
- Upwards of 80% of coastal wetlands will be destroyed.
- Atlantic coast finfish and shellfish, which account for 80% of U.S. fisheries, will diminish.
- Southeastern forests, which provide half the nation's hardwoods and softwoods, will decline.
- Urban air quality will deteriorate, as higher summer temperatures drive pollution levels over air quality standards for longer periods of time.
- Agriculture and livestock losses will be experienced throughout the lower-Midwest as droughts increase in frequency.
- Water availability will be less predictable; increasing the costs of water supply for irrigation, hydropower, and urban use.
- Floods, hurricanes, and forest fires will occur more frequently.
- Upwards of $300 billion in additional powerplants will be needed to provide power for air-conditioning to deal with the increasing temperatures.

For other nations the future looks even worse. The Maldive Islands, for example, could disappear if the projected increases in sea level are realized. Adapting to these social and financial disasters is both unacceptable and unnecessary. We can make choices about our future and not leave it to fate. It is the choices that we can make that I want to discuss today.

12.3 THE CHALLENGE: MAKE CHOICES THAT SPUR ECONOMIC PROSPERITY WITHOUT GENERATING DANGEROUS LEVELS OF GREENHOUSE GASES

Ideally, each choice we make--each step we take--should spur multiple benefits that simultaneously alleviate or resolve the manifold problems noted above. This is preventive management, which is a sharp contrast to the widespread practice of crisis management. It is a public policy approach that U.S. Representative Claudine Schneider has been promoting in the Congress for 8 years.

Leading climate authority, Dr. Stephen Schneider at the National Center for Atmospheric Research, spells out just such an approach in his book, *The Coevolution of Climate and Life*. Dr. Schneider refers to it as the "tie-in" strategy--that is, take those actions that reduce greenhouse gases and that also tie-in with solving other problems or in providing multiple benefits. Two years of congressional testimony by leading authorities on this problem makes one thing clear:

- The available options for reducing greenhouse gases like carbon dioxide (which accounts for half the problem) range in cost by a factor of 10 or more.

- In these tight financial times, we need to approach this problem with fiscal responsibility.

- We need to rank the options for cutting carbon emissions in a cost-effective order.

That is the essence of Representative Schneider's legislation--The Global Warming Prevention Act (HR 1078)--which is cosponsored by over 130 U.S. Representatives, including 7 full committee chairmen and over 50 subcommittee chairmen. It is imperative that we adopt several dozen policy measures that establish a rigorous least-cost energy planning process throughout the Federal Government.

We do not want to repeat the federal energy mistakes of the 1970s, where we responded to the energy crisis with an $88 billion fiscal disaster known as the Synthetic Fuels Corporation. Adherence to rigorous least-cost energy planning gives every indication of creating wealth and reducing carbon emissions at the same time.

12.4 MULTIPLE BENEFITS OF ENERGY EFFICIENCY OVER PAST 15 YEARS

The scientific and engineering communities in the United States unwittingly took up exactly this challenge of designing multibeneficial remedies in the wake of the 1973 Arab oil embargo. Consider the most successful example--energy efficiency improvements to our stock of buildings, factories, vehicles, and appliances. Over the past 15 years, these improvements have

- reduced the energy needed to produce a dollar of gross national product by 33%

- reduced carbon emissions by 50% below what they would have been without these improvements

- saved (and continue to save) Americans $160 billion per year

- reduced foreign oil imports by 66%

- helped collapse world oil prices, reduce OPEC's power, and ease energy-fanned inflation rates

- reduced the trade deficit by more than $50 billion per year

- enhanced U.S. productivity by reducing the cost of producing goods and services

- contributed to U.S. global competitiveness by creating a steady flow of energy-efficient products and technologies

- improved capital formation by tens of billions of dollars per year by lowering investment needs in new energy facilities as energy growth rates declined.

The pace of technological advancements show no signs of abating. Energy efficiency is the cash cow for the United States and the rest of the world. We need to keep on milking it. While some global warming is inevitable because of past and current greenhouse emissions, a growing consensus of leading authorities confidently conclude that there are no technological barriers to solving the global warming problem. Moreover, solving the problem need not be economically onerous, if well-crafted public policies encourage the market to pursue the least-cost options available.

12.5 CAUSES OF GLOBAL CLIMATE CHANGE

Global climate change is being caused by numerous human actions.

- Burning fossil fuels contributes 50% of the greenhouse gases.
- Burning tropical forests adds 10 to 20%.
- Ozone-depleting chlorofluorocarbons add about 20%.
- Other greenhouse gases like methane and nitrous oxides result from various human activities like landfills, rice cultivation, fertilizer use, and increasing animal populations.
- Finally, whether the human population finally stabilizes at 8 billion or 14 billion will determine whether greenhouse gas levels are much higher or lower.

12.6 GLOBAL ENERGY SCENARIOS FOR NEXT 50 YEARS

Each of these problems deserves time before this audience. I want to focus on the largest culprit, energy consumption patterns, because it offers tremendous opportunities for saving money, which could then be available for helping to solve all the other pressing problems.

Problems With the Business-As-Usual Scenario

If we continue global energy expansion in a business-as-usual manner, within the lifespan of today's high school student the world will witness a 2- to 4-fold increase in energy consumption. Supplying energy to meet this increased demand would require:

- the equivalent of a new Alaskan pipeline every 1 to 2 months
- a 1000 Megawatt coal powerplant every 1.5 to 2 days
- a 1000 Megawatt nuclear powerplant every 4 to 6 days
- 4 to 9 million pounds of weapons-grade plutonium put into commercial transit each year, as shortages of uranium supplies require breeder reactors (this is enough material to produce 400,000 to 700,000 atomic bombs annually)
- a doubling of OPEC capacity to maximum output (oil price increases have historically occurred when OPEC capacity exceeds 80%, and Middle East conflicts and oil disruptions are likely to increase since most remaining cheap oil reserves are in the Middle East)

This increase in energy consumption would also result in:

- a tripling of carbon emissions from combusted fossil fuels
- a doubling of atmospheric carbon dioxide levels early next century
- consumption of large fraction of investment capital (developing countries will need to increase their export earnings by a staggering 15% per year beyond inflation, just to finance energy development)
- no guarantee that basic human needs will be addressed, which is imperative if population stabilization and halting tropical deforestation are to occur.

Benefits of Higher Efficiency Scenario

In sharp contrast, pursuing cost-effective efficiency investments generate multiple benefits instead of multiple problems.

- Oil consumption would decline, as would dependence on OPEC oil.

- Carbon emissions would decline from today's level, instead of increasing more than 300%.

- Nuclear power production would plateau at the equivalent of 460 large nuclear reactors (460,000 megawatts), with no net new additions after the year 2000 (a sharp contrast with conventional forecasts that predict the number of needed reactors to be 5 to 10 times that level).

- There would be no need for breeder reactors or weapons-grade plutonium.

- Energy savings would continue to rise until they surpass a staggering $500 billion per year.

- Energy savings would become a key source of capital formation for meeting basic human needs and for developing the industrial infrastructure necessary for sustaining economic growth.

- Basic human needs are more likely to be satisfied by this end-use-oriented, least-cost energy strategy, than in the "trickle-down" energy approach that typically ignores this problem.

- By meeting basic human needs, incomes would rise, fertility rates would fall, and population stabilization would occur more rapidly, thus preventing an estimated 700 million births over the next 50 years.

- The combined effects of efficiency gains and population declines would greatly diminish the rate of tropical deforestation, species extinction, and environmental destruction

Illustrative Example: Lighting

Consider a few dramatic illustrations of what can be achieved through low-cost efficiency improvements. Take the ubiquitous light bulb, which was a revolutionary advancement from the humble candle but which is itself succumbing to solid-state electronics and space-age materials as illustrated in the following discussions.

Compact Fluorescent Light Benefits

Compact fluorescent lights range in size from 5 to 32 watts. They displace incandescent light bulbs that consume four or more times the amount of electricity to deliver similar levels of light and last 1/10 as long. Using compact fluorescent lights would save a commercial building over $50 per ampere in electricity costs, demand charges, replacement bulbs, and labor savings in changing bulbs. It would also prevent combustion of 400 pounds of coal; production of 25 pounds of sulphur dioxide, an acid rain pollutant; and production of 25 milligrams of plutonium and half a curie of radioactive wastes, if the electricity were generated by a nuclear power plant.

The compact fluorescent light is impressive, and sales have been brisk--doubling every 24 months. The Osram assembly line in Maybrook, New York, like the Sylvania plant in Massachusetts, the Phillips plant in New Jersey, and the Panasonic and General Electric plants elsewhere, each annually produce several million compact fluorescent lights. The combined output of two of these assembly lines would rank them as a top 50 coal producer in the United States. However, there is one essential difference; with compact fluorescent lights, consumers reap a million dollar savings while 3 million tons of coal go uncombusted.

Imaging Specular Reflectors

The 3-M Company, Alcoa, and others have developed another lighting advancement called the imaging specular reflector. This is a fancy word for creating a mirror-like surface that bounces more light out of fluorescent lighting fixtures. Two imaging specular reflectors put out the same amount of light as four to six standard fluorescent lights. Used in office buildings, the reflectors result in huge stacks of unneeded, delamped tubes. Each tube reaps the building owner $25 per year in savings.

Daylighting

With the advent of solid-state lighting ballasts and other electronic and photosensing systems, commercial and industrial buildings are now capable of dimming their lights to take advantage of skylight, which can supply 25% to 50% of their daytime lighting needs. The Albany County Airport in Colonie, New York, is a good example; it gets 40% of its lighting and 20% of its heating from a skylight solar court. Southern California Edison has helped more than 50 of its customers implement daylighting designs, because implementing that practice is 90% cheaper than building new power plants.

The Power of Lighting Efficiency

I've talked a good deal about lighting, for good reason. Efficient lighting creates wealth and cuts carbon emissions at the same time. The equivalent of nearly half of all coal burned by U.S. utilities goes for lighting and the associated air conditioning required to offset the heat generated from inefficient lights. The market now has several dozen kinds of highly efficient lighting technologies that, when fully used, will deliver the same lighting services, but reduce lighting electrical consumption by more than 80%, save consumers over $25 billion per year, and prevent the combustion of tens to hundreds of millions of tons of coal per year.

Super-Efficient Windows

Lighting offers just one of many energy-saving opportunities. The windows in America's buildings are another energy guzzler. They leak the equivalent of an Alaskan pipeline--nearly 2 million barrels of oil per day. As a result of a joint federal/private research and development effort in the 1970s, super-efficient windows that are approaching the same heat-retaining ability of walls are now available.

Full use of these "heat mirror" windows in U.S. buildings will eventually replace a volume of oil that is equivalent to the capacity of the Alaskan pipeline, save consumers several billion dollars per year, and prevent the combustion of over 50 million tons of carbon per year.

Energy-Efficient Refrigerators

Food cooling consumes nearly 25% of residential electricity, more than lighting and cooking combined. The refrigerator is another energy guzzler. The average model consumes 2 to 10 times more electricity than highly efficient models and burns its volume in coal each year, while an efficient model reduces the volume of coal consumed to a vegetable bin's worth.

On a nationwide basis, refrigerators require an electrical generation output of 25,000 megawatts. By replacing our current inefficient refrigerators with efficient models, we could reduce our current coal-fired electricity production by from 7% to 13%, which would prevent the combustion of 30 to 57 million tons of coal per year.

The Sunfrost refrigerator is a state-of-the-art design that consumes up to 90% less electricity than comparable-sized models in conventional-design refrigerators. Currently, the Sunfrost is marketed exclusively to rural households that use photovoltaic power systems. Because it is hand made, the refrigerator currently costs several times more than comparable-sized conventional models, but it saves rural households $10,000 to $20,000 on photovoltaic arrays. When mass manufactured, it is expected to cost no more than current-design inefficient models.

Other refrigerator manufacturers, like Whirlpool, Amana, and General Electric, produce models that have cut electrical consumption by 50%. The payback period for these models is within 2 years because of reduced utility bills. That is an excellent return on investment--better than a 50% return on the capital investment. The energy savings will recoup the entire cost of the refrigerator, and then some, over its useful life. The return on investment far exceeds that on passbook savings accounts or on investments in stocks and bonds.

Building All-Electric Efficient Homes That Use 80% Less Electricity

Technological advancements have make it possible for virtually every energy-consuming device to produce more work and services with less and less energy input. It is possible to get huge energy savings in an all-electric home with all the modern conveniences and use 80% less electricity, as Table 12.1 illustrates.

Fuel Efficient Vehicles

The U.S. transportation sector consumes nearly 66% of all the oil used in this country, and is responsible for about 33% of the carbon dioxide emissions.

Table 12.1. Energy-Efficient Household (watts per person)

End-Use	Household at Present		More Efficient Technologies in 1982-1983[a]	
	U.S., 1980	Sweden, 1982	U.S.	Sweden
Furnace	890	900	60	65
Air Conditioner	46	–	65	–
Hot Water	280	180	43	110
Refrigerator	79	17	25	8
Freezer	23	26	21	17
Stove	62	26	21	16
Lighting	41	30	18	9
Other	80	63	75	41
Total	1,501	1,242	328	266
(percentage)	(100%)	(100%)	(21%)	(21%)

(a) Based on all electric, four-person household, 2000 square feet. (Goldembert et al., *Energy for a Sustainable World*).

Tremendous efficiency advances have been made to cars, trucks, buses, airplanes, and trains, and many more opportunities remain available. Improving the efficiency of the all-pervasive automobile is especially important. The 150 million light cars and trucks in the United States consume more than 2 billion barrels of oil each year and combust their weight in carbon each year.

According to a 1988 study by the Natural Resources Defense Council, *Fact Sheet on Oil and Conservation Resources*, 15 billion barrels of oil could be saved over the next three decades by gradually increasing fuel economy through 1998 from the current 27 miles per gallon (mpg) to 45 mpg for new light vehicles, and from the less than 20 mpg to 30 mpg for new light trucks. Twenty-two billion barrels of oil could be saved by 2020 if fuel economy were gradually increased through 2008 to 60 mpg for light vehicles and 45 mpg for light trucks. These cost-effective improvements would prevent combustion of between 1 and 2 billion tons of carbon (that is, 4 to 8 billion tons of carbon dioxide).

A thorough review of the opportunities by auto efficiency expert Deborah Bleviss (*The New Oil Crisis and Fuel Economy Technologies*, Quoram Books, 1988), indicates that the cost of improvements would amount to about the same as, or less than, an automobile radio, with a payback with several years resulting from gasoline savings. The improvements would substantially reduce our dependence on foreign oil imports, which may account for 66% of U.S. oil use within the decade. The billions of barrels saved could also help cut the trade deficit by hundreds of billions of dollars over the coming decades.

Half a dozen auto companies have built and road tested prototypes that consume from 60 to 135 mpg. Volvo's LCP 2000 achieves a combined city/highway mileage of 75 mpg, exceeds EPA crash tests, and is projected to cost no more to produce than current models. The Toyota AXV, a 4 to 5 passenger car, gets 98 mpg combined city/highway mileage. It achieves its high mileage through the systematic application of presently available technologies, such as extensive use of light-weight plastics and aluminum, lower aerodynamic drag, a direct-injection engine, and a continuously variable transmission. Renault's Vesta, which was road tested in 1987, achieved a gasoline consumption rate of 145 mpg.

Technologically, the future looks extremely promising given the development of space age composite plastics that are crash resistant; more durable, stronger, and lighter metal alloys that are corrosion resistant; and ceramic engine parts that burn fuels cleaner and more efficiently. We can confidently speak of a future fleet of vehicles that can be super efficient, safe, and clean operating, and also provide other consumer amenities like comfort and performances.

Industrial Savings

The industrial sector contributes about 33% of the current carbon emissions. Not surprisingly, enormous energy savings remain to be achieved in this sector, whether in processing steel, glass, plastics, aluminum, chemicals, or in fabricating and finishing manufactured goods.

A ton of U.S. steel, for example, requires 75% more energy to produce than an equivalent amount produced using Swedish techniques, and over 200% more energy than a ton produced using the emerging technologies like Plasma smelting. Studies indicate tremendous potential for a wide range of industries to simultaneously cut energy and other raw material inputs, hazardous waste outputs, and capital and labor requirements. The Global Warming Prevention Act includes funding for establishing 10 research centers that concentrate on achieving these multiple benefits.

Increasing U.S. recycling efforts is also essential. Not only does recycling cut our waste stream and the cost of safely disposing of trash, but remanufacturing recyclable wastes into reusable materials requires only a fraction of the energy used in the original manufacture of a product: 90% to 97% less energy for remanufacturing aluminum; 90% to 95% less for plastics; 50% to 70% less for steels; 30% to 50% less for paper; and 5% to 30% less for glass.

Recycling results in multiple benefits. Recycled wastes reduce air and water pollution 95% and 97% for aluminum; 85% and 76% for steel; 74% and 35% for paper; and 20% for glass. Moreover, most people are unaware that paper products comprise half of all wood harvested, yet only 25% of all paper is currently recycled.

According to a 1988 study by Howard Geller of the American Council for an Energy Efficient Economy and Neil Seldman of the Institute for Local Self-Reliance, by increasing the rate of recycling by 10% above the projected level for 1992, and 30% above the projected level for 2008, the United States could realize energy savings equal to more than 1 billion barrels of oil and $30 billion in savings.

Summary of Efficiency Potential

One cannot repeat often enough: Energy efficiency is a cash cow we need to milk. According to repeated testimony before Congress, an estimated $200 billion per year remains to be saved in the United States through efficiency investments in buildings, factories, and vehicles.

12.7 WHAT ABOUT SUPPLY-SIDE OPTIONS?

Efficiency investments not only save money and cut emissions, but they buy us time to develop lower cost, lower risk supply-side options. I want to mention two of these options that have received little or no press treatment: aircraft-derived gas turbines and renewable resources.

U.S Air Force Research and Development Program to Develop Efficient Aircraft Engines

With little fanfare, the U.S. Air Force has spent $5 billion on research and development over the past decade (and continues to spend $500 million each year) on highly efficient, durable turbine engines for aircraft developed by General Electric and Pratt-Whitney. The United States has the world lead on this technology. Only recently has it been realized that these turbines would make excellent electrical generators.

Studies show that slight modification would make the turbines 40% more efficient that current powerplants. They cost less to build and operate than coal or nuclear plants, even if gas prices double or triple. For fuel, they could use natural gas, which emits nearly half the carbon dioxide of coal, no sulphurdioxide, and very low nitrogen oxides, or biomass, a renewable harvested fuel that would not add any new carbon emissions to the atmosphere.

In fact, Southern California Edison is now meeting with General Electric, the California Energy Commission, the California Public Utility Commission, and the Southern California Air Quality Board about using this technology. They believe that these turbines--known as intercooled steam-injected gas turbines--can displace more than 5,000 megawatts of currently operating oil and gas powerplants in Southern California Edison's service area; reduce NOx emissions from 200 parts per million to 10 ppm, greatly improving air quality; and reduce customers' utility bills. This is a win-win approach of cutting multiple emissions and costs at the same time. Not only is this technology valuable for improving urban air quality, reducing acid rain emissions, and slowing greenhouse gas emissions, but it has an immediate export opportunity.

The Agency for International Development (AID) has completed a study that found this technology has a ready market in the 70 countries with sugar processing factories. Used in a cogeneration mode, improved turbines could meet 100% of the factories' mechanical, electrical, and steam-processing needs; generate an additional 50,000 megawatts (this is equivalent to all of the oil-fired electricity in these developing countries); and use sugar wastes and other renewable resources like tree crops as the fuel source, which would generate enormous capital savings because these fuel sources are so much cheaper than the conventional primary fuel sources (i.e., imported oil or coal).

Again, following our criteria of seeking choices that result in multiple benefits, promotion of improved turbine technology would achieve a reduction in the U.S. trade deficit by exploiting our world lead in this technology; a reduction in the export earnings required by debt-ridden developing countries to expand the energy sector; and an increase in the number of local jobs per dollar of energy investment.

Renewable Resources

Sustainably harvested renewable resources do not add carbon to the atmosphere, but in fact, serve as reservoirs by capturing and storing carbon dioxide in plants, while also protecting watersheds and reducing soil erosion.

Tree-Crop Economics

It is noteworthy what is already being done with tree crops in developing countries. Brazil, India, and the Philippines are world leaders in using tree crops and other biomass plants as fuels. Their costs are running at around $6 to $9 per barrel of oil displaced--about half the price of imported oil.

What about the total energy needs of developing countries? A pervasive misconception is that efficiency is great for the industrialized nations, but cannot be expected to offer much to developing countries. It is argued that: 1) industrialized countries use 10 times more energy than developing countries; 2) efficiency investments would cost a lot of money, something in short supply in these debt-ridden countries; and 3) importing efficient technologies from industrialized countries would only worsen their trade deficits.

Fortunately, the detailed global-energy efficiency study mentioned above reached a completely different conclusion. Because developing countries are just beginning to build their factories, buildings, etc., they have an opportunity to install the most energy efficient technologies. For example, buildings and factories can be built to use half as much energy as in the past. In many cases, these energy-efficient buildings can be built at no extra initial cost.

Many of the efficiency technologies I've mentioned are applicable in many parts of the developing world, like in extremely inefficient tourist hotels and in commercial and public office buildings. Even among the poor, energy use is extremely inefficient. Developing countries offer enormous opportunities for resource savings through efficiency improvements. Freed-up resources could then be used more productively in other parts of the economy.

Most importantly, efficiency investments are 5 to 10 times cheaper than conventional energy investments. The global energy efficiency study, *Energy for a Sustainable World*, found that developing countries could raise their standard of living to that of a West European country in the 1970s, while keeping energy consumption at the very low current levels. How is this possible?

Consider the stone fireplace, which is still used by over one billion people. It is only 5% efficient, compared with a U.S. gas stove that is 80% efficient. Using stone fireplaces requires each person to combust as much wood each year as a West European automobile combusts in gasoline. This highly inefficient use of a renewable resource is a major cause of deforestation.

The long term goal is to implement a transition to the use of high-efficiency stoves. The immediate goal is to quadruple the efficiency of the current stoves. Models are available, constructed by local people out of local materials that payback within two months. Multiple benefits include saving women and children several hours per day of wood gathering; greatly reducing respiratory illnesses as a result of sharp drops in smoke emissions; and freeing up the biomass resources for more efficient uses, like the gas turbines mentioned above.

The savings opportunity from more efficient wood stoves is enormous. Allocating just $1 billion per year for 10 years, would provide enough funds for loans to over 1 billion people in poor rural areas to build and purchase these more efficient stoves. At the same time, it would free up enough renewable resources to generate 160,000 megawatts of electricity. This is a least-cost situation at its very best.

Potential for Renewable Resources Even Greater

Thus far, I have focused my discussion of renewable resources on their uses in developing countries, because they already provide 50% to 75% or more of energy needs in many of these countries. However, the U.S. gets nearly 10% of its total energy needs from renewable resources--mostly hydropower and wood. I have already noted the potential for greatly increasing and expanding the use of renewable resources in developing countries. Now, I will discuss an expanded role for these resources in the United States.

It is a little known fact that, according to the Department of Energy's 1985 report, *Renewable Energy Research and Development Outlook*, renewables comprise one of America's largest energy resource bases--5 to 10 times larger than coal. With a stable-funded research and development effort over the next 25 years, we could expect to economically extract 85 quads of energy, which would be enough to provide over 75% of the total U.S. energy needs by then. Unfortunately, the Federal Government has slashed the renewable resources research and development budget by 75% and abandoned all leadership on developing this resource.

Yet, many renewable resources are cost-effective today when compared with fossil and nuclear resources; wind power; solar heated buildings; solar thermal collectors for generating peak electricity; biomass fuels in the paper and forest products industry; photovoltaics in diverse, remote settings; additional turbines at existing hydrodams; tree-plantings an urban settings that passively cool buildings and reduce the urban heat island effect; and daylighting, which can provide 25% to 50% of a building's daytime lighting requirements.

Photovoltaic cells (commonly known as solar cells) remain one of the most exciting renewable technologies, particularly amorphous silicon cells. Solar cells are made from sand, which is one of the earth's most abundant materials. We've often heard how one ton of uranium ore used in a breeder nuclear reactor can eliminate 70 tons of coal. Well, one ton of sand used as silicon on solar cells can eliminate 500,000 tons of coal.

Fifteen years ago theoretical physicists did not even know about amorphous silicon cells. Since then, efficiency gains for this material have steadily climbed, while the price of production has steadily fallen. Amorphous silicon cells are fast replacing the crystalline solar cells, which require a hundred times more silicon. A forthcoming report by the World Resources Institute, by Dr. Joan Ogden and Dr. Robert Williams, shows that it is feasible to talk about using solar cells to economically generate carbon-free hydrogen fuels for vehicles within the next 12 years.

Hydrogen, which can be produced with photovoltaic technology, is a multibeneficial fuel that can slow the greenhouse warming effect, reduce urban ozone, and reduce acid rain pollutants. If this country doesn't develop photovoltaic-generated hydrogen fuels, we can be assured that the Japanese will. Japan surpassed the United States last year in marketing solar cells worldwide.

Long-Term Scenario Assumptions of Energy Services

By developing policies that encourage the purchase of the most efficient energy-consuming devices available, it is possible for even the poorest nations to spur economic development without massive energy growth. Conventional energy projections of 1000% increases or more are simply unnecessary.

Quite the contrary, hundreds of billions of dollars would be saved, which may be the only source of capital for meeting basic human needs and developing the industrial infrastructure necessary to sustain economic development.

12.8 MARKET BARRIERS TO LEAST-COST AND LOW-RISK OPTIONS

Although efficiency and renewable resources have impressive track records, and present compelling reasons for increasing their use, they continue to face formidable barriers. Inappropriate market signals pose a major barrier to cost-effective investments. This is due to lavish subsidies to producers (more than $40 billion per year in the United States, over 90% to fossil and nuclear fuels), as well as price control subsidies for consumers (more than 50% below true market cost in many developing countries).

Another serious barrier stems from the gap between high consumer discount rates versus low producer discount rates. Consumers require a 1- to 2-year payback period on investments, whereas energy producers and utilities look for a 20- to 30-year payback period. This creates a "payback gap" that prevents implementation of many cost-effective efficiency measures.

An equally daunting barrier confronts low-income consumers such as elderly people on fixed incomes, or cash-strapped companies, who lack investment capital to make cost-effective efficiency improvements. Renters also face a treacherous impasse, since they lack the incentive to invest in the owners' buildings, while owners don't invest in energy-efficient upgrades because they don't reap the benefits of reduced energy bills typically paid by the renters.

A major market problem is the failure to incorporate the manifold external social costs incurred by various energy resources (for example, global warming, acid rain, foreign oil dependency, nuclear proliferation, intergenerational radioactive waste disposal, etc.). According to one estimate provided by Dr. Veziroglu of the Clean Energy Research Institute during a June 1988 hearing by the House Committee on Science, Space, and Technology on global warming, the health costs and environmental deterioration incurred from using fossil fuels exceeds their actual cost (over $40 per barrel). The societal cost to the nation from continued use of fossil fuels could amount to several hundred billion dollars per year.

Another market imperfection involves an inadequate effort on research and development, which tends to be inherently weak and short-sighted in the private sector. Private energy research and development declined sharply this past decade in parallel with the decline in federal energy research and development programs.

12.9 POLICY CHANGES NEEDED

What kind of policies do we need to implement to get the market vigorously involved in these nongreenhouse options?

- Eliminate subsidies for energy supplies, or shift subsidies to efficiency and solar/renewable technologies so they get equal consideration.

- Adopt least-cost energy planning policies, similar to the Pacific Northwest model.

- Factor in social costs due to environmental deterioration, energy security, etc., in order to choose truly low-cost, low-risk energy options. The Pacific Northwest planning model acknowledges these social costs by providing energy conservation with a 10% bonus; the State of Wisconsin is currently doing this in developing its energy future through a program called Not Easily Estimated Dollar Savings (NEEDS).

- Assert vigorous leadership in developing environmentally benign renewable resources. Reverse the trend of past 8 years that witnessed a 75% cut in the U.S. research and development budget.

- Adopt least-cost planning procedures, such as giving cash rebates to customers to invest in energy-efficient technologies, practices, etc.

- Support research and development on energy efficiency and renewable resources, including government sponsored competitions, joint efforts with the private sector, and joint research with other nations.

- Improve fuel economy of vehicles, along with increasing the "gas-guzzler" tax on inefficient vehicles, and tax rebates for consumers to purchase efficient vehicles.

- Adopt as standard operating procedures the upgrading of a home with cost-effective efficiency improvements at the time of sale. These upgrades would then be reflected in a home energy rating label.

These and many other policy changes are vital to retard global warming. They span a range from international protocols for establishing carbon dioxide reduction goals, to individual efforts on recycling and becoming smart shoppers for energy-efficient products.

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