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# Global Environmental Security: Research and Policy Strategies for the 1990s

Michael A. Lazaro and Hua Wang
Environmental Assessment and Information Sciences Division
Argonne National Laboratory
Argonne, Illinois, USA

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## ABSTRACT

*The subject of global environmental change is emerging as one of the most hotly debated international issues for the 1990s. In fact, our earth system has undergone a nature-induced gradual change in climate on both a temporal scale that spans over millions of years and a spatial scale ranging from regional to transcontinental. Pollutant emissions associated with population growth and industrial activities manifest the anthropogenic climatic forcing that has been superimposed on the background of natural climate fluctuations. Our incomplete understanding of the global impacts of environmental pollution on the earth systems (atmosphere, biosphere, hydrosphere, cryosphere, and lithosphere), however, make the prediction of the timing, magnitude, and patterns of future global change uncertain. Though there exist many uncertainties, we do not have the luxury of deferring all action before the predicted changes are known with more certainty or until their environmental consequences become irreversible. A coherent, stable and flexible policy is needed to provide a foundation for coordinated international-interagency programs of observations, research, analysis, and international negotiation toward a policy consensus concerning global environmental protection.*

*This paper examines the science and policy background of global environmental change. The major scientific uncertainties and policy issues confronting decision makers are identified; and the scientific framework, as well as current national and international research programs aimed at resolving the scientific uncertainties, are discussed. A coherent, stable, and flexible policy is needed to provide a foundation for coordinated international-interagency programs of observation, research, analysis, and international negotiation toward a policy consensus concerning global environmental security. On the basis of what is currently known about global change, recommendations are presented on both near-term and long-term policy option decisions.*

## INTRODUCTION

Environmental pollution is not constrained by political boundaries. It has been recognized that the long-range transport of air pollutants and their buildup in the atmosphere may cause global climatological modification and ecological devastation. The various global environmental issues that have waxed and waned for decades include acid rain, stratospheric ozone depletion, global warming, and others [1]. Acid rain is conceived as a regional, and possibly global, threat to the earth's ecosystems. The global mean concentration of carbon dioxide in the atmosphere is a leading indicator of the global warming trend and the atmospheric release of chlorofluorocarbons (CFCs) has been linked to the depletion of the earth's protective ozone layer in the stratosphere.

Historically, the term "acid rain", also known as "acid precipitation", was first introduced in the 1850s to describe the sooty skies over England and the acidity found in local precipitation. Modern interest in acid rain as an environmental issue dates back to the 1960s. The first reports on the stratospheric ozone depletion due to fluorocarbon propellant releases from aerosol spray cans and on global warming due to carbon dioxide buildup in the atmosphere occurred during the 1970s.

Acid precipitation results from atmospheric emissions of sulfur dioxide and nitrogen oxides. Precipitation becomes acidic when sulfur dioxide and nitrogen oxides in the atmosphere react with moisture, through the atmospheric oxidation processes, to form dilute solutions of sulfuric and nitric acids. Acid precipitation serves as perhaps the best example of how a form of pollution can cause transboundary political strife. Its geographical distribution is largely restricted to highly industrialized areas of the northern hemisphere, but it has the potential to expand to a near-global scale in the future. The environmental effects of acid precipitation on aquatic and terrestrial ecosystems and on public welfare are diverse and widespread, including acidification of lakes, demineralization of soils, reduction in forest productivity, injury to agricultural corps, deterioration of buildings and structures, and impairment of visibility.

Stratospheric ozone depletion has been linked to both the presence of polar stratospheric clouds (high-altitude clouds made of ice crystals and nitric acid that form over Antarctica in the winter) and the atmospheric emissions of CFCs, halons, carbon tetrachloride, and methyl chloride -- which are synthetic chemicals widely used as refrigerants, as cleaning solvents, and for other industrial applications. With polar stratospheric clouds as a pivotal catalyst, these chemicals can quickly break down to release chlorine gas and to destroy ozone molecules.

The cause of global warming has been traced to the presence of carbon dioxide, methane, CFCs, nitrous oxide, and other gases in the atmosphere; these gases block the earth's heat from escaping back into space, forming a "greenhouse" effect. The increasing consumption of fossil fuels contributes directly to the rise in atmospheric carbon dioxide levels, and human destruction of natural vegetation disrupts the normal carbon cycle that allows carbon dioxide to be converted into carbon and oxygen.

The global impact of the global environmental issues discussed above intensifies with increasing energy production and use, industrial activities, and population. In fact, the world's fossil energy consumption has increased more than 50 percent since 1970 to $3.0 \times 10^{20}$ joules, and the population has doubled over the last 40 years to 5.3 billion in 1990 [2]. Over 70 percent of sulfur dioxide is emitted from coal-fired power plants and nearly 50 percent of the nitrogen oxides from the growing fleet of automobiles worldwide. In the United States alone, approximately 20 million metric tons each of sulfur dioxide and nitrogen oxides are being emitted into the atmosphere annually [3]. From 1950 to 1980, worldwide carbon dioxide emissions more than tripled, and their global contribution has occurred in parallel with the growth of industrialization. North America and Western Europe together accounted for about 68 percent of carbon dioxide emissions in 1950 but represented only about 45 percent of the expanded total in 1989 [2]. During the same period, the portion attributable to developing countries in Africa, Asia, and Latin America grew from 7 percent to over 20 percent of the world total. The U.S. worldwide contribution in 1989 is about 25 percent, shared in approximately equal approportions by electric power production, industrial processes, and transportation sectors [4].

International acid rain control was initiated in 1985 with the ratification of Helsinki Sulfur Protocol by 20 countries and in 1988 with the ratification of the *Sofia Nitrogen Oxides Protocol* by 18 countries. The Helsinki Protocol commits governments to reduce their transboundary sulfur dioxide emissions by 30% from 1980 to 1993. Revisions to the protocol being prepared, as of early 1991, aim at further reductions after the 1993 target year. The SOFIA Protocol calls for a "freeze" of nitrogen oxide emissions at 1987 levels (1978 levels for the United States) in 1994. A recent additional declaration to this protocol, signed by 12 countries, commits them to a 30% reduction by 1998. Ozone depletion chemicals are being phased out from worldwide production and use, as mandated in the 1987 *Montreal Protocol to Control Substances that Deplete the Ozone Layer* and its subsequent 1990 *London Amendments*. With the United Nations Conference on Environment and Development (also known as the "Earth Summit") held in Rio de Janeiro, Brazil in June 1992, attention is now being focused on globe change, in particular on global warming, and its potential impacts to the earth system (atmosphere, biosphere, hydrosphere, cryosphere, and lithosphere).

## SCIENCE AND POLICY - ISSUES OF UNCERTAINTY

Worldwide releases of greenhouse gases (GHGs), most notably carbon dioxide, methane, CFCs, and nitrous oxide are changing the global atmospheric concentrations of these gases. According to a recent National Academy of Sciences study [5], carbon dioxide is the greatest contributor to the greenhouse effect at about 49 percent, followed by methane at 18 percent, CFCs at 15 percent, and nitrous oxide at 6 percent. Nitrogen oxides, carbon monoxide, and ground-level ozone make up the remaining 13 percent of the greenhouse effect. Carbon dioxide, carbon monoxide, and nitrogen oxides are produced primarily from fossil-fuel combustion of stationary and mobile sources; methane from rice cultivation, livestock, natural gas leaks, and other agricultural and industrial processes; CFCs from synthetic chemical compounds used for refrigeration, air conditioning, foam production, and solvents; nitrous oxide from fertilizers; and ozone from precursor gases of nitrogen oxides and volatile organic compounds.

The atmospheric GHG concentrations have been steadily increasing as a result of energy generation, transportation, and industrial, agricultural and other societal activities. Figure 1 depicts the long-term (1750-1990) trends of global mean atmospheric concentrations for four key GHGs -- carbon dioxide ($CO_2$), methane ($CH_4$), CFC-11, and nitrous oxide ($N_2O$) [6]. The data show that carbon dioxide, methane and nitrous oxide maintained a steady and gradual increase through the 1950s but have risen sharply since then. No CFCs were present in the atmosphere before the 1930s. The current global mean global concentration and trend, and the estimated residence time for major GHGs and possible future CFC substitutes, are summarized in Table 1 [6,7].

Analysis of the global surface temperature variations between 1950 and 1988 reveals that the global mean temperature may have already risen by more than 1 $^{o}$C since the beginning of this century [3]. If population growth and energy consumption continue at the present pace, it has been estimated that human activities will have added sufficient quantities of GHGs to cause significant climatic modification by the year 2030, equivalent to an effective doubling of carbon dioxide alone since the preindustrial period [8]. Recent studies suggest that the global mean temperature could rise by 0.15 to 0.3 $^{o}$C per decade during the next century [9].

Our current understanding of the relationship between GHG emissions and their long-term impact on global change is inadequate to address such important questions as: (1) the atmospheric, oceanic, and biospheric mechanisms in the global carbon cycle; (2) the role of atmospheric clouds in regulating the earth's energy budget; and (3) the atmospheric chemical processes and their interaction with global change. For scenarios in which no GHG emission reductions or controls would be imposed, the major uncertainty lies in projecting future increases in atmospheric GHG concentrations, because of uncertainties in quantifying emissions from energy, agriculture, and other human activities. For scenarios in which GHG emissions would be regulated, the greatest uncertainty lies in our understanding of the global fluxes into and out of the biosphere and oceans.

The current policy debate is fueled by scientific uncertainties, including the apparent lack of a definitive signal of global change and the perception by some that any immediate action would be premature and costly. These uncertainties must be identified and clarified, if possible, prior to developing or formulating long-term policy options for global environmental security. However, based on what we presently know, short-term policy measures can and should be implemented immediately.

**Figure 1 Major Trends in Atmospheric GHG Concentrations, 1750-1990 [6]**

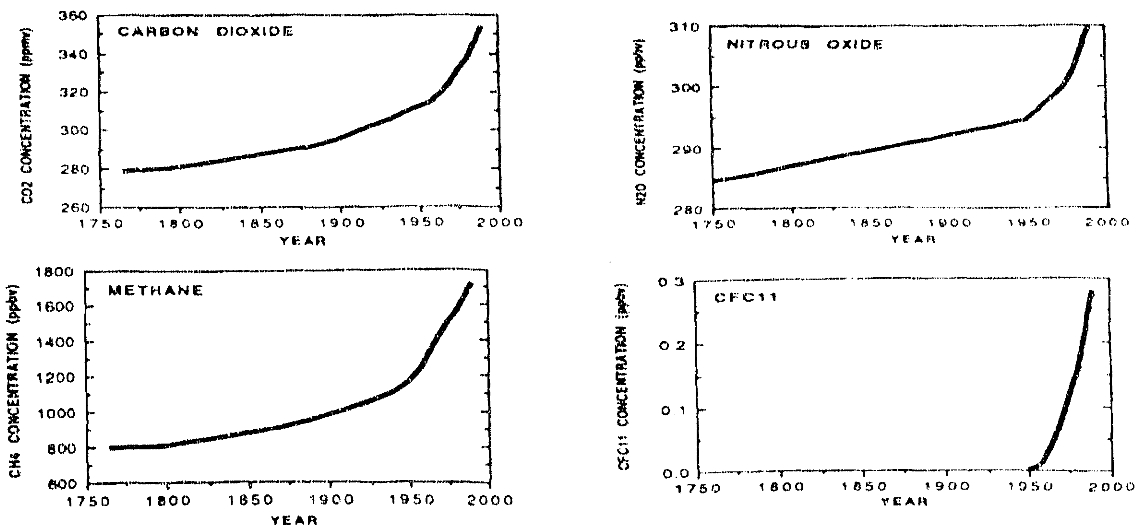

Table 1 Radiative Forcing ($\Delta F$) Relative to $CO_2$ per Unit Molecule Change and per Unit Mass Change in the Atmosphere for Various Greenhouse Gases [8,9]

| Greenhouse Gas (GHG) | $\Delta F$ per Unit Molecule Relative to $CO_2$ | $\Delta F$ per Unit Mass Relative to $CO_2$ | Global Concentration[a] ($ppm_v$) | Residence Time (yr) |
|---|---|---|---|---|
| $CO_2$ | 1 | 1 | $3.5 \times 10^2$ | 100-250 |
| $CH_4$ | 21 | 58 | $1.7 \times 10^0$ | 10 |
| $N_2O$ | 206 | 206 | $3.1 \times 10^{-1}$ | 150 |
| CFC-11 | 12,400 | 3,970 | $2.8 \times 10^{-4}$ | 65 |
| CFC-12 | 15,800 | 5,750 | $4.8 \times 10^{-4}$ | 120 |
| CFC-113 | 15,800 | 3,710 | $6.0 \times 10^{-5}$ | ~0 |
| CFC-114 | 18,300 | 4,710 | N/O | 200 |
| CFC-115 | 14,500 | 4,130 | $5.0 \times 10^{-6}$ | 400 |
| HCFC-22 | 10,700 | 5,440 | $1.2 \times 10^{-4}$ | 15 |
| $CCl_4$ | 5,720 | 1,640 | $1.5 \times 10^{-4}$ | 40 |
| $CH_3CCl_3$ | 2,730 | 900 | $1.6 \times 10^{-4}$ | 6 |
| $CF_3Br$ | 16,000 | 4,730 | $2.0 \times 10^{-6}$ | 110 |
| Possible CFC substitutes | | | | |
| HCFC-123 | 9,940 | 2,860 | N/A | 1.6 |
| HCFC-124 | 10,800 | 3,480 | N/A | 6.6 |
| HFC-125 | 13,400 | 4,920 | N/A | 28 |
| HFC-134a | 9,570 | 4,130 | N/A | 16 |
| HCFC-141b | 7,710 | 2,900 | N/A | 8 |
| HCFC-142b | 10,200 | 4,470 | N/A | 19 |
| HFC-143a | 7,830 | 4,100 | N/A | 41 |
| HFC-152a | 6,590 | 4,390 | N/A | 1.7 |

[a] *N/O - not observed, calculated, or available; N/A - not applicable.*

The following facts are known with a reasonable to high degree of certainty:

- The earth's climate has undergone natural changes over the past million years. Without the naturally occurring greenhouse effect, primarily from carbon dioxide and water vapor, the global mean temperature of the earth's surface could be 33 °C cooler.
- The influence of human activities superimposing on the naturally occurring climate changes becomes significant only after the 1950s.
- Changes in atmospheric GHG concentrations are closely correlated to the change in the surface mean temperature of the earth.
- Several GHGs -- such as carbon dioxide, nitrous oxide, and CFCs -- have long atmospheric lifetimes of several decades to centuries (see Table 1). As a consequence, atmospheric concentrations of these gases will respond slowly to any policy decision to reduce their emissions.
- Some of the GHGs are more effective at influencing climate change than others. For example, carbon dioxide is responsible for about half of the enhanced greenhouse effect over the last century.
- A global warming potential (GWP) can be reasonably estimated for each GHG, based on its atmospheric concentration, potency for solar and terrestrial heat absorption, and residence time.

The following issues are not known or not understood with any reasonable degree of certainty:

- Estimating the budgets (sources and sinks) for several key GHGs -- such as methane, carbon monoxide, nitrous oxide, and nitrogen dioxide -- with the possible exception of carbon dioxide and CFCs.
- Assessing the impact of regional patterns on future global change, especially precipitation.
- The role played by clouds in regulating the earth's energy budget.
- The role played by ocean dynamics as the greatest single climate-feedback system.
- The role of atmospheric chemical processes and atmospheric-ocean interaction on globe change.
- The influence of future major natural events (e.g., volcanic eruptions, forest fires, etc.) on globe change.
- The complex interactions between global change and the earth's ecosystems.
- Various assumptions and mechanisms employed in existing general circulation models for accurate and reliable globe change predictions [10].

The above lists of certainties and uncertainties are not comprehensive. They are presented to highlight the status of knowledge concerning the global change issue.

## SCIENTIFIC RESEARCH FRAMEWORK

The complexity of global change and its potential long-term impact indicate that a profound transformation is required in the study of earth science. Until recently, earth science has been advanced largely through the pursuit of independent disciplines, such as meteorology, oceanography, geology, etc.; each concerned primarily with a specific earth component. Global connection among the various earth's components began to take shape in the last decade in the form of "earth system science" -- a new approach that combines traditional, independent earth science disciplines into a dynamically integrated earth system. Fundamental to this new approach is viewing the whole earth as an interrelated and dynamic set of processes that operate on a wide range of spatial and temporal scales. Because of the interactions among the various earth components, changing one component will certainly affect others, both in space and time [11].

The necessity for understanding our global environment, its natural variability, and the changes imposed on it through human activities has been recognized internationally. The increasing concerns about global change have resulted in unprecedented and concerted international efforts. Scientific planning for research on international global change proceeds primarily through the International Council of Scientific Unions (ICSU) and its committees, such as the Scientific Committee on Oceanic Research, the Scientific Committee for the International Geosphere-Biosphere Programme, and the International Social Science Council Committee on the Human Dimensions of Global Environmental Change. Planning also proceeds through intergovernmental organizations such as the World Meteorological Organization (WMO) and the United Nations Environmental Programme.

In 1980, ICSU and WMO jointly established the *World Climate Research Programme* (WCRP) to promote scientific research on physical climatic processes and to develop a capability for predicting climatic variations. The main goals of the programme are to determine the extent to which transient climatic variations are predictable and to lay the scientific foundation for predicting the response of the earth's climate to natural or human-induced influences. Major WCRP projects now under way or planned for the near future include: (1) the *Global Energy and Water Cycles Experiment* (GEWEX); (2) the *World Ocean Circulation Experiment* (WOCE); (3) the *Tropical Ocean and Global Atmosphere Programme* (TOGA); (4) the *World Ozone Program (WOP)*; (5) the *International Satellite Cloud Climatology Project* (ISCCP); and (6) the *International Satellite Land Surface Climatology Project* (ISLSCP). Each of these programs includes a range of projects to study specific aspects or physical processes of the earth system. For example, the ISCCP is designed to determine the quantitative effect of clouds on the earth's radiation balance and the ISLSCP to assess the interaction of climate with land surface processes.

In addition, ICSU launched the *International Geosphere and Biosphere Programme* (IGBP) in 1986. The IGBP is designed to provide the scientific information needed to explore the future of the earth in the next 100 years. It stresses understanding of the processes that govern the evolution of the earth in time scales of years to decades, and it focuses on the dynamic processes that connect the land, ocean, and atmosphere. It crosses traditional boundaries of geophysics, geochemistry, and biology and, above all, promotes the exchange of scientists and data across national frontiers. The programme will last for at least a decade and will involve the interplay between modeling and measurements, field projects and process studies, and theory and experiment. Ten core research projects are currently being conducted under the IGBP [12,13]. Among them, the *Joint Global Ocean Flux Study* (JGOFS), the *International Global Atmospheric Chemistry Programme* (IGACP), and the *Global Change and Terrestrial Ecosystems (GCTE)* are designed to investigate GHG controls by the oceanic and terrestrial biospheres.

In 1989, the Committee on Earth and Environmental Sciences (CEES), a consortium formed by several U.S. federal agencies, established the *Global Change Research Program* (USGCRP) [14]. There are nine CEES science-funding entities: the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), the Smithsonian Institution, and the Departments of Agriculture, Defense, Energy, and Interior. The specific objectives of the program are:

- To establish an integrated, comprehensive long-term program of documenting the earth system on a global scale.
- To conduct a program of focused studies to improve our understanding of the physical, geological, chemical, biological, and social processes that influence earth system processes and trends on global and regional scales.
- To develop integrated conceptual and predictive earth system models.

The USGCRP is prioritized into seven major scientific research areas: (1) climate and hydrological systems; (2) bio-geochemical dynamics; (3) ecological systems and dynamics; (4) earth system history; (5) human interactions; (6) solid earth processes; and (7) solar influences. It represents an integrated U.S. research effort with the goal of establishing the scientific basis for national and international policymaking related to natural and human-induced global changes. A pivotal part of the USGCRP is NASA's *Earth Observing System* (EOS) program, known as "Mission to Earth." Beginning in 1998, NASA will launch a series of earth-observing satellites to collect needed information and data for "earth system science" studies over a period of 15 years.

The above-described globe change programs are the result of many years of planning and represent consensus of the international scientific community regarding the maturity of the fundamentals of these projects and the readiness of the world's nations to commit to these timely endeavors. The scientific strategy to achieve effective prediction of the behavior of the earth system as a whole must be based on a combination of earth system studies, remote-sensing observations, and modeling. Several areas of scientific uncertainty -- dealing primarily with improving our current understanding of the earth system (e.g., climate feedback mechanisms) -- need to be addressed by the research programs. The following four areas are considered the most critical [6]:

1. Control of greenhouse gases by the earth system;
2. Control of water budget and radiation by clouds, precipitation, and evaporation;
3. Control of the transport and storage of heat by the ocean; and
4. Control as a source and sink of greenhouse gases and moisture exchange through ecosystem processes.

## POLICY OPTIONS FRAMEWORK

As previously discussed, it is widely recognized that predictions of climate change contain considerable uncertainties. A major question for policymakers, therefore, is whether it is sensible to take action now, despite uncertainties, or to wait until the science is better defined through accelerated research efforts. The concern is that if atmospheric GHG concentrations continue to rise at the current rate, global change would occur at some irreversible point that would have major impact on the earth's atmosphere-ocean-lithosphere-biosphere system and on human society as a whole [15].

Effective policy planning and implementation in a global change program require extensive national and international participation, cooperation, and interaction. As indicated earlier, a series of recent international actions have been focused on globe change. The initiatives and the primary resources in these efforts have come largely from countries other than the United States, even though the United States is responsible for a disproportionate share of the GHG emissions. In 1987, the United Nation Environmental Programme called on governments to develop "foreign policy for the environment" that would enable developing nations to achieve their economic aspirations while protecting the global environment [16]. In June 1988, at the Conference on the Changing Atmosphere in Toronto, a petition was made for "immediate actions ... to counter the ongoing degradation of the atmosphere." In 1989, the Science Committee of the North Atlantic Treaty Organization, citing the need for truly interdisciplinary research, initiated a new study of climate change and its effects. Also in 1989, leaders of 17 nations issued "The Declaration of The Hague," calling for a new international institution within the United Nations with powers to limit emissions of carbon dioxide and other gases. This led most recently in June 1992 to the "Earth Summit" in Brazil, at which world leaders discussed a proposed *Joint Agenda 21 for Sustainable Development.*

The international action with the greatest prospect for explicit results was the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988. This panel was charged with presenting a plan to the Second World Climate Conference in September 1990 for limiting GHG emissions. This was intended to lead to an international convention on global change. Reports of key working groups on science (headed by Britain), impacts (headed by the USSR), and response strategies (headed by the United States) were issued in June 1990 [6]. Although the Science Working Group reported that the "longer emissions continue to increase at present day rates, the greater reductions would have to be for concentrations to stabilize", the response of the U.S.-led Strategy Working Group was that "individual nations may wish to consider taking steps now to limit GHG emissions." Additionally, U.S. policy issues contained in the CEES reports are addressed in very general terms, and the intimate connections between global change and energy policy are not addressed explicitly. This is disappointing because effective coupling is essential to enlighten budgetary decisions, to clarify policy options, to ensure that regulatory or preventive measures are soundly based, and to provide guidance for international negotiations. As a consequence, the United States has been often criticized as "not well prepared for negotiations at an international convention on climate change" [17].

Possibilities for human response to global change generally revolve around four sets of options: *prevention, abatement, adaptation, and mitigation.* Pollution *prevention* is the strategy of encouraging changed patterns of energy use that, in turn, would contribute to reduced GHG emissions. Examples include changing from fossil-fuel use to renewable and/or nuclear energy options and more efficient use and conservation of fossil fuels. Emission *abatement* or reduction is the traditional approach used for decades in industrialized countries. This approach relies on costly post-emission, "end-of-pipe" source controls that usually impose a significant energy penalty. *Abatement* technologies have, for the most part, been applied traditionally to the cleanup of local environmental pollution problems. The *adaptation* policy option is that of allowing the earth system to evolve and then adapting human systems to the changing environment, and perhaps also assisting natural systems to adapt. For example, a long-term action to cope with sea-level rise could be a retreat from the shoreline. The last category of response options and maybe the most controversial, *mitigation* or more precisely "*geoengineering*", is generally recognized as a category of options for reducing the GHG impact on the environment. It involves the deliberate manipulation of climate forcing to keep climate in a desired state, in contrast to *abatement* which reduces anthropogenic forcing. Proposals to increase the earth's albedo to compensate for radiation heating due to increasing atmospheric concentrations would seek to counteract the heating effects without reducing GHG emissions. Another *geoengineering* approach would be the removal of carbon dioxide from the atmosphere by planting biomass to offset emissions.

To some extent, the distinction among *prevention*, *abatement*, *adaptation*, and *mitigation* represents a sequential range of possibilities, depending on how advanced the process of global change is when an action is taken. However, the viewed extremes of *abatement* and *adaptation* have become polar positions of policy advocates, each regarding the other as morally irresponsible for advocating either precipitous action or irreversible delay, respectively. To reach a consensus toward common ground in the policy debate, a framework to address global change should primarily encompass *prevention*-based strategies. Near-term strategies should be proactive and emphasize approaches that will incur minimal costs or eventually produce cost savings. Long-term strategies should emphasize improved energy efficiency and introduce innovative non-GHG producing technologies. *Abatement, adaptation*, and *mitigation* options should be factored in, as needed.

According to the IPCC response strategies working group [18], the single most significant anthropogenic source of global warming is energy production, conversion, and utilization. These sources, which contributed to 46% of the total radiative forcing during the 1980s, include production and conversion in electricity generation, and consumption in industrial, transportation and commercial/residential sectors. The production and use of CFCs and other halocarbons in various industrial, military, and commercial processes account for 24% of the greenhouse effect. Deforestation, biomass burning and other changes in land-use practices contribute about 18% of the man-induced radiative forcing, with the remaining coming from agricultural practices and other human activities.

Over the near-term, (before year 2000) the human response to global change should concentrate on pollution prevention measures in energy production and use that should be done regardless of any global change threat. These measures should emphasize energy conservation and efficient energy utilization for sustainable global economic growth. This is especially important for developing countries.

Significant GHG source reductions from current levels for each of the following energy sectors can be achieved in the near term through implementation of a variety of the pollution *prevention* measures:

Power Generation and Industry Sectors

- Increased conversion and production efficiency through introduction of improved boilers, integrated gasification combined cycle systems, and atmospheric and fluidized bed combustion.
- Improved systems for cogeneration of electricity and steam and enhanced operation and maintenance.
- Commercial introduction of advanced technologies such as fuel cells and photovoltaics.
- Improvement and acceleration, where feasible of the introduction of renewable energy sources such as advanced solar collectors, wind turbines and geothermal projects.
- Promotion of further efficiency improvements in industrial production processes.
- Substitution with lower energy intensive industry materials.

Transportation and Building Sectors

- Increase fuel efficiency of road vehicles through advanced vehicle aerodynamic, material composition, combustion chamber, tire, and lubricant design.
- Introduction of improved public transportation systems such as high-speed urban and intra-urban/suburban trains and increase the intra-urban shift from private autos to van/car pools, buses and rail lines.
- Increase the introduction of flexible alternative fueled vehicles, and introduce electric vehicles.
- Promotion of the increased introduction of efficient residential/commercial lighting (e.g., compact florescent bulbs), heating and cooling systems (e.g., solar, underground heat pumps), and appliances (especially for refrigeration).

For the long term, aggressive development of near-commercial pollution *prevention* technologies between now and the year 2025 will ensure that non-carbon dioxide-emitting facilities will be available for installation in the post-2025 period. Their deployment could eliminate GHG emissions from the electric power sector by 2050. The long-term actions are as follows:

Power Generation and Industry Sectors

- Improve and accelerate the commercialization of fuel cells and photovoltaics.
- Improve energy conversion efficiencies through compressed air and superconducting energy storage.
- Develop and commercialize advanced industrial process technologies and increase the use of less energy-intensive materials for industry.
- Accelerate research and commercial development of advanced safe integrated fuel-cycle nuclear reactors such as the Integral Fast Reactor Program initiated at Argonne National Laboratory.
- Develop and introduce advanced solar and wind power technologies, and advanced fuel cell technologies.

Transportation and Building Sector

- Increase development and production of electric vehicles with electricity c[illegible]ning from nuclear or renewable-energy generating stations.

- Increase vehicle fuel efficiency encourage use of more efficient vehicle fleets and systems.
- Improve building energy storage use systems through the use of information technology to anticipated and safety energy needs.
- Develop advanced battery systems for both transportation and building sectors.
- Develop and introduce alternative food storage systems that eliminate refrigeration requirements.

## CONCLUSIONS

Although there is significant degree of understanding about the earth's radiation balance, including the GHGs responsible for disrupting this balance and the global trends in GHG concentrations; substantial uncertainty in forecasting global change still exists. The critical areas of uncertainty in understanding earth system processes involve a lack of adequate understanding of the role of clouds, ocean and atmosphere dynamics, hydrosphere-atmosphere-biosphere coupling, and their respective feedback mechanisms. The lack of adequate treatment of these processes in general circulation models leaves considerable uncertainty in the accurate prediction of the timing, regional patterns, type, and magnitude of climate change. The social and economic costs associated with global change will be measured in terms of changes in the frequency and intensity of extreme climate events, such as hurricanes, tidal surges, tornadoes, floods, droughts, etc. Small changes in global mean air surface temperature can be adapted to easily by humans, but successive years of drought or a sequence of severe storms are much less easily handled by modern society. Given the uncertainty in the state-of the-science, the ability to reasonably forecast the frequency and intensity of extreme events in a radiatively forced atmosphere poses a nearly insurmountable challenge.

Reducing the scientific uncertainty will require long-term collaborative international research efforts, such as those established with the World Climate Research Programme and the International Geosphere-Biosphere Programme. Although the goal of these programs is to establish the scientific basis for national and international policy-making, the delay of all policy-decisions until the research provides this foundation is not the their intended objective. The decision on how and when to act ultimately lies with world leaders.

As an aid to policy decision makers scientific research should be coupled with a cooperative international economic-environmental policy objective for "sustainable development". This policy objective should be viewed as a insurance policy for global environmental security. Sustainable development should emphasize effective family planning to slow and reverse the growth in world population. The control of this growth is critical to implementing feasible policies sustainable food and energy supplies, and sustainable global biodiversity. The complexity of these issues, especially the population problem will require hard social and political decisions. However, "no regrets" policy decisions that could be make relatively easily now for reasons other than the likelihood of significant of global change should focus on achieving sustainable energy supplies well into the 21st century. This policy should be based on both near-term and long-term "pollution prevention" measures that involve small costs to net economic benefits. The near-term strategy should be proactive and rely primarily on enhancing energy conservation and efficiency measures in global energy production, conversion, and utilization. This would include adoption of cost saving energy efficiency measures in power generation and industrial production through the introduction of improvements in process design and material substitution. Vehicle engineering design improvements and incentives to encourage a significant shift in the mode of urban commuter traffic could save significant energy resources in the transportation sector, and improved material design and material substitution would do the same in the residential and commercial building sectors. Long-term measures would include steps to significantly increase fossil energy conservation through conversion to non-GHG technologies in all energy sectors.

The policy debate about the controversial uncertainties of global change and its potential consequences is substantial and politically interesting. However, these uncertainties should not be considered relevant to proactive policy decision. Near-term and in most cases economically advantages actions maybe sufficient to address the global environmental threat if it does exist and highly beneficial even if it doesn't. The problems with the issue of global change should not be viewed as decision making under uncertainty but viewed in this instance as a valuable opportunity for significant and needed change to national and global energy policy.

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