

I. THE SCIENCE OF GLOBAL CHANGE:

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE 1992 IPCC SUPPLEMENT*

February, 1992

SECTION II. SCIENTIFIC ASSESSMENT BY WORKING GROUP I

2. Our Major Conclusions

Findings of scientific research since 1990 do not affect our fundamental understanding of the science of the greenhouse effect and either confirm or do not justify alteration of the major conclusions of the first IPCC Scientific Assessment, in particular the following:

- emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons, and nitrous oxide;
- the evidence from the modelling studies, from observations and the sensitivity analyses indicate that the sensitivity of global mean surface temperature to doubling CO₂ is unlikely to lie outside the range 1.5° to 4.5°C;
- there are many uncertainties in our predictions particularly with regard to the timing, magnitude and regional patterns of climate change due to our incomplete understanding;
- global mean surface air temperature has increased by 0.3 to 0.6°C over the last 100 years;
- the size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability. Thus the observed increase could be largely due to this natural variability; alternatively this variability and other human factors could have offset a still larger human-induced greenhouse warming;

*The following document contains excerpts from Intergovernmental Panel on Climate Change, WMO/UNEP, 1992 IPCC Supplement (Feb. 1992). Passages have been selected from the reports of Working Group I (Scientific Assessment), Working Group II (Potential Impacts of Climate Change), and Working Group III (Response Strategies). The original paragraph numbering system has been retained for ease of reference.

- the unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more.

There are also a number of significant new findings and conclusions which we summarize as follows:

Gases and Aerosols

- Depletion of ozone in the lower stratosphere in the middle and high latitudes results in a decrease in radiative forcing which is believed to be comparable in magnitude to the radiative forcing contribution of chlorofluorocarbons (CFCs) (globally-averaged) over the last decade or so.
- The cooling effect of aerosols* resulting from sulphur emissions may have offset a significant part of the greenhouse warming in the Northern Hemisphere (NH) during the past several decades. Although this phenomenon was recognized in the 1990 report, some progress has been made in quantifying its effects.
- The Global Warming Potential (GWP) remains a useful concept but its practical utility for many gases depends on adequate quantification of the indirect effects as well as the direct. We now recognize that there is increased uncertainty in the calculation of GWPs, particularly in the indirect components and, whilst indirect GWPs are likely to be significant for some gases, the numerical estimates in this Supplementary Report are limited to direct GWPs.
- Whilst the rates of increase in the atmospheric concentrations of many greenhouse gases have continued to grow or remain steady, those of methane and some halogen compounds have slowed.
- Some data indicate that global emissions of methane from rice paddies may amount to less than previously estimated.

Scenarios

- Steps have been taken towards a more comprehensive analysis of the dependence of future greenhouse gas emissions on socio-economic assumptions and projections. A set of updated scenarios have been developed for use in modelling studies which describe a wide range of possible future emissions in the absence of coordinated policy response to climate change.

*The scientific definition of "aerosol" is an airborne particle or collection of particles, but the word has become associated, erroneously, with the propellant used in "aerosol sprays". Throughout this report the term "aerosol" means airborne particle or particles.

Modelling

- Climate models have continued to improve in respect of both their physical realism and their ability to simulate present climate on large scales, and new techniques are being developed for the simulation of regional climate.
- Transient (time-dependent) simulations with coupled ocean-atmospheric (CGCMs), in which neither aerosols nor ozone changes have been included, suggest a rate of global warming that is consistent, within the range of uncertainties, with the 0.3°C per decade warming rate quoted by IPCC (1990) for Scenario A of greenhouse gas emissions.
- The large-scale geographical patterns of warming produced by the transient model runs with CGCMs are generally similar to the patterns produced by the earlier equilibrium models except that the transient simulations show reduced warming over the northern North Atlantic and the southern oceans near Antarctica.
- CGCMs are capable of reproducing some features of atmospheric variability on intra-decadal time-scales.
- Our understanding of some climate feedbacks and their incorporation in the models has improved. In particular, there has been some clarification of the role of upper tropospheric water vapour. The role of other processes, in particular cloud effects, remains unsolved.

Climate Observations

- The anomalously high global mean surface temperatures of the late 1980s have continued into 1990 and 1991 which are the warmest years in the record.
- Average warming over parts of the Northern Hemisphere mid-latitude continents has been found to be largely characterized by increases in minimum (night-time) rather than maximum (daytime) temperatures.
- Radiosonde data indicate that the lower troposphere has warmed over recent decades. Since meaningful trends cannot be assessed over periods as short as a decade, the widely reported disagreements between decadal trends of air temperature from satellite and surface data cannot be confirmed because the trends are statistically indistinguishable.
- The volcanic eruption of Mount Pinatubo in 1991 is expected to lead to transitory stratospheric warming. With less certainty, because of

other natural influences, surface and tropospheric cooling may occur during the next few years.

- Average warming over the Northern Hemisphere during the last four decades has not been uniform, with marked seasonal and geographic variations; this warming has been especially slow, or absent, over the extratropical northwest Atlantic.
- The consistency between observations of global temperature changes over the past century and model simulations of the warming due to greenhouse gases over the same period is improved if allowance is made for the increasing evidence of a cooling effect due to sulphate aerosols and stratospheric ozone depletion.

The above conclusions have implications for future projections of global warming and somewhat modify the estimated rate of warming of 0.3°C per decade for the greenhouse gas emissions Scenario A of the IPCC 1990 Report. If sulphur emissions continue to increase, this warming rate is likely to be reduced, significantly in the Northern Hemisphere, by an amount dependent on the future magnitude and regional distribution of the emissions. Because sulphate aerosols are very short-lived in the atmosphere their effect on global warming rapidly adjusts to increases or decreases in emissions. It should also be noted that while partially offsetting the greenhouse warming, the sulphur emissions are also responsible for acid rain and other environmental effects. There is a further small net reduction likely in the rate of global warming during the next few decades due to decreases in stratospheric ozone, partially offset by increases in tropospheric ozone.

Research carried out since the 1990 IPCC Assessment has served to improve our appreciation of key uncertainties. There is a continuing need for increased monitoring and research into climate processes and modelling. This must involve, in particular, strengthened international collaborations through the World Climate Research Programme (WCRP), the International Geosphere Biosphere Programme (IGBP) and the Global Climate Observing System (GCOS).

How does the climate system work, and what information do we need to estimate future changes?

How does the climate system work?

The Earth absorbs radiation from the Sun, mainly at the surface. This energy is then redistributed by the atmosphere and ocean and re-radiated to space at longer (“thermal”, “terrestrial” or “infrared”) wavelengths. Some of the thermal radiation is absorbed by radiatively-active (“greenhouse”) gases in the atmosphere, principally water vapour, but also carbon dioxide,

methane, the CFCs, ozone and other greenhouse gases. The absorbed energy is re-radiated in all directions, downwards as well as upwards such that the radiation that is eventually lost to space is from higher, colder levels in the atmosphere. . . . The result is that the surface loses less heat to space than it would do in the absence of greenhouse gases and consequently stays warmer than it would otherwise be. This phenomenon, which acts rather like a "blanket" around the Earth, is known as the greenhouse effect.

What factors can change climate?

Any factor which alters the radiation received from the Sun or lost to space, or which alters the redistribution of energy within the atmosphere, and between the atmosphere, land and ocean, will affect climate.

The Sun's output of energy is known to change by small amounts over an 11-year cycle, and variations over longer periods may occur. On time-scales of tens to thousands of years, slow variations in the Earth's orbit have led to changes in the seasonal and latitudinal distribution of solar radiation; these changes have played an important part in controlling the variations of past climate.

Increases in the concentration of the greenhouse gases will reduce the efficiency with which the Earth cools to space and will tend to warm the lower atmosphere and surface. The amount of warming depends on the size of the increase in concentration of each greenhouse gas, the radiative properties of the gases involved, and the concentration of other greenhouse gases already present in the atmosphere. It also can depend on local effects such as the variation with height of the concentration of the greenhouse gas, a consideration that may be particularly germane to water vapour which is not uniformly mixed throughout the atmosphere. The effect is not a simple one and the balance which is struck between these factors depends on many aspects of the climate system.

Aerosols (small particles) from volcanoes, emissions of sulphates from industry and other sources can absorb and reflect radiation. Moreover, changes in aerosol concentrations can alter cloud reflectivity through their effect on cloud properties. In most cases aerosols tend to cool climate. In general, they have a much shorter lifetime than greenhouse gases so their concentrations respond much more quickly to changes in emissions.

Any changes in the radiative balance of the Earth, including those due to an increase in greenhouse gases or in aerosols, will tend to alter atmospheric and oceanic temperatures and the associated circulation and weather patterns. However climate varies naturally on all time-scales due to both external and internal factors. To distinguish man-made climate variations from those natural changes, it is necessary to identify the man-made "signal" against the background "noise" of natural climate variability.

A necessary starting point for prediction of changes in climate due to increases in greenhouse gases and aerosols is an estimate of their future

concentrations. This requires a knowledge of both the strengths of their sources (natural and man-made) and also the mechanisms of their eventual removal from the atmosphere (their sinks). The projections of future concentrations can then be used in climate models to estimate the climatic response. We also need to determine whether or not the predicted changes will be noticeable above the natural variations in climate. Finally, observations are essential in order to monitor climate, to study climatic processes and to help in the development and validation of models.

Recent Improvements in Scientific Understanding

3. How has our Understanding of Sources and Sinks of Greenhouse Gases and Aerosols Changed?

During the last eighteen months there have been a number of important advances in our understanding of greenhouse gases and aerosols. These advances include an improved quantitative understanding of the atmospheric distributions, trends, sources and sinks of greenhouse gases, their precursors and aerosols, and an improved understanding of the processes controlling their global budgets.

Atmospheric Concentrations and Trends of Long-lived Greenhouse Gases: The atmospheric concentrations of the major long-lived greenhouse gases [carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), chlorofluorocarbons (CFCs), and carbon tetrachloride (CCl₄)] continue to increase because of human activities. While the growth rates of most of these gases have been steady or increasing over the past decade, that of CH₄ and some of the halocarbons has been decreasing. The rate for CH₄ has declined from about 20 ppbv/yr in the late 1970s to possibly as low as 10 ppbv/yr in 1989. While a number of hypotheses have been forwarded to explain these observations, none is completely satisfactory.

Atmospheric Concentrations and Trends of other Gases that Influence the Radiative Budget: Ozone (O₃) is an effective greenhouse gas both in the stratosphere and in the troposphere. Significant decreases have been observed during the last one to two decades in total column O₃ at all latitudes—except the tropics—in spring, summer and winter. The downward trends were larger during the 1980s than in the 1970s. These decreases have occurred predominantly in the lower stratosphere (below 25km), where the rate of decrease has been up to 10% per decade depending on altitude. In addition, there is evidence to indicate that O₃ levels in the troposphere up to 10km altitude above the few existing ozonesonde stations at northern middle latitudes have increased by about 10% per decade over the past two decades. Also, the abundance of carbon monoxide (CO) appears to be increasing in the NH at about 1% per year. However, there is little new

information on the global trends of other tropospheric O₃ precursors, (non-methane hydrocarbons (NMHC) and oxides of nitrogen (NO_x)).

Sources and Sinks of Carbon Dioxide: The two primary sources of observed increase in atmospheric CO₂ are combustion of fossil fuels and land-use changes; cement production is a further important source.

The emission of CO₂ from the combustion of fossil fuels grew between 1987 and 1989. Preliminary data from 1990 indicate similar emissions to 1989. The best estimate for global fossil fuel emissions in 1989 and 1990 is 6.0 +/- 0.5 GtC,* compared to 5.7 +/- 0.5 GtC in 1987 (IPCC, 1990). The estimated total release of carbon in the form of CO₂ from oil well fires in Kuwait during 1991 was 0.065 GtC, about one percent of total annual anthropogenic emissions.

The direct net flux of CO₂ from land use changes (primarily deforestation) integrated over time, depends upon the area of land deforested, the rate of reforestation and afforestation, the carbon density of the original and replacement forests, and the fate of above-ground and soil carbon. These and other factors are needed to estimate annual net emissions but significant uncertainties exist in our quantitative knowledge of them. Since IPCC (1990) some progress has been made in reducing the uncertainties associated with the rate of deforestation, at least in Brazil. A comprehensive, multi-year, high spatial resolution satellite data set has been used to estimate that the average rate of deforestation in the Brazilian Amazonian forest between 1978 and 1989 was 2.1 million hectares (Mha) per year. The rate increased between 1978 and the mid-1980s, and has decreased to 1.4 Mha/yr in 1990. The Food and Agriculture Organization (FAO), using information supplied by individual countries, recently estimated that the rate of global tropical deforestation in closed and open canopy forests for the period 1981-1990 was about 17 Mha/yr, approximately 50% higher than in the period 1976-1980.

Despite the new information regarding rates of deforestation, the uncertainties in estimating CO₂ emissions are so large that there is no strong reason to revise the IPCC 1990 estimate of annual average net flux to the atmosphere of 1.6 +/- 1.0 GtC from land-use change during the decade of the 1980s.

Since IPCC (1990) particular attention has focused on understanding the processes controlling the release and uptake of CO₂ from both the terrestrial biosphere and the oceans, and on the quantification of the fluxes. Based on models and the atmospheric distribution of CO₂, it appears that there is a small net addition of carbon to the atmosphere from the equatorial region, a combination of outgassing of CO₂ from the warm tropical waters and a terrestrial biospheric component that is the residual between large sources (including deforestation) and sinks. There appears to be a strong Northern

*1 GtC (gigatonne of carbon) equals one billion [one thousand million (10⁹)] tonnes of carbon.

Hemisphere sink, containing both oceanic and terrestrial biospheric components, and a weak Southern Hemisphere (SH) sink. The previous IPCC global estimate for an ocean sink of 2.0 ± 0.8 GtC per year is still a reasonable one. The terrestrial biospheric processes which are suggested as contributing to the sinks are sequestration due to forest regeneration, and fertilization arising from the effects of both CO₂ and nitrogen (N), but none of these can be adequately quantified. This implies that the imbalance (of order 1-2 GtC/yr) between sources and sinks, i.e. "the missing sink", has not yet been resolved. This fact has significant consequences for estimates of future atmospheric CO₂ concentrations . . . and the analysis of the concept of the Greenhouse Warming Potential. . . .

Sources of Methane: A total (anthropogenic plus natural) annual emission of CH₄ of about 500Tg can be deduced from the magnitude of its sinks combined with its rate of accumulation in the atmosphere. While the sum of the individual sources is consistent with a total of 500Tg CH₄, there are still many uncertainties in accurately quantifying the magnitude of emissions from individual sources. Significant new information includes a revised rate of removal of CH₄ by atmospheric hydroxyl (OH) radicals (because of a lower rate constant), a new evaluation of some of the sources (e.g., from rice fields) and the addition of new sources (e.g., animal and domestic waste). Recent CH₄ isotopic studies suggest that approximately 100Tg CH₄ (20% of the total CH₄ source) is of fossil origin, largely from the coal, oil, and natural gas industries. Recent studies of CH₄ emissions from rice agriculture, in particular Japan, India, Australia, Thailand and China, show that the emissions depend on growing conditions, particularly soil characteristics, and vary significantly. While the overall uncertainty in the magnitude of global emissions from rice agriculture remains large, a detailed analysis now suggests significantly lower annual emissions than reported in IPCC 1990. The latest estimates of the atmospheric lifetime of CH₄ is about 11 years.

Sources of Nitrous Oxide: Adipic acid (nylon) production, nitric acid production and automobiles with three-way catalysts have been identified as possibly significant anthropogenic global sources of nitrous oxide. However, the sum of all known anthropogenic and natural sources is still barely sufficient to balance the calculated atmospheric sink or to explain the observed increase in the atmospheric abundance of N₂O.

Sources of Halogenated Species: The worldwide consumption of CFCs 11, 12, and 113 is now 40% below 1986 levels, substantially below the amounts permitted under the Montreal Protocol. Further reductions are mandated by the 1990 London Amendments to the Montreal Protocol. As CFCs are phased out, HCFCs and HFCs will substitute, but at lower emission rates.

Stratospheric Ozone Depletion: Even if the control measures of the 1990 London amendments to the Montreal Protocol were to be implemented by all nations, the abundance of stratospheric chlorine and bromine will increase over the next several years. The Antarctic ozone hole, caused by industrial halocarbons, will therefore recur each spring. In addition, as the weight of evidence suggests that these gases are also responsible for the observed reductions in middle- and high-latitude stratospheric O₃, the depletion at these latitudes is predicted to continue unabated through the 1990s.

Sources of Precursors of Tropospheric Ozone: Little new information is available regarding the tropospheric ozone precursors (CO, NMHC, and NO_x), all of which have significant natural and anthropogenic sources. Their detailed budgets therefore remain uncertain.

Sources of Aerosols: Industrial activity, biomass burning, volcanic eruptions, and sub-sonic aircraft contribute substantially to the formation of tropospheric and stratospheric aerosols. Industrial activities are concentrated in the Northern Hemisphere where their impact on tropospheric sulphate aerosols is greatest. Sulphur emissions, which are due in large part to combustion effluents, have a similar emissions history to that of anthropogenic CO₂. Estimates of emissions of natural sulphur compounds have been reduced from previous figures, thereby placing more emphasis on the anthropogenic contribution.

SECTION III. ASSESSMENT OF POTENTIAL IMPACTS OF CLIMATE CHANGE

BY WORKING GROUP II

The energy, human settlement, transport and industrial sectors, human health and air quality

Recent studies for the Maldives and for the Pacific island states including Tuvalu, Kiribati, Tokelau and the Marshall Islands have reconfirmed that small low-lying island states and large populations living in low-lying coastal areas will be increasingly vulnerable, particularly if adaptive measures are inadequate, to the combination of sea level rise, storm surges and coastal flooding.

The high dependency on biomass and hydroelectric energy in many developing countries indicates that these countries are quite sensitive to the impacts of climate change. Biomass production, on which developing countries such as Bangladesh depend for 90 to 100% of their energy needs, could be damaged by a combination of climate-change-induced drought or inundation.

On the other hand, there has been little work that has shed new light on the question of socioeconomic impacts in the areas of energy, human settlement, transport and industrial sectors, human health and air quality.

A UK study shows soil shrinkage and swelling as a result of climate change in clay-rich areas has major implications for the construction and insurance industries and for human settlement. Water-dependent industries such as food processing, paper making and power generation could be affected by hydrological changes under changed climate conditions.

Knowledge of climate change on human health has extended and confirmed the previously reported results with greater understanding of potential shifts in disease vector habitats with global warming particularly in New Zealand and Australia. Diseases such as malaria, lymphatic filariases, schistosomiasis, leishmaniasis, onchocerciasis (river blindness), dengue fever, and Australian and Japanese encephalitis could increase or be reintroduced in many countries as a consequence of global warming. Regarding the impact of UV-B radiation on health, recent studies show that it affects the human immunosuppression system and vision.

Agriculture and Forestry

New studies, such as those in the European Community, North America, and Southeast Asia highlight the IPCC 1990 conclusions that impacts will vary greatly depending on the extent of climate change and on the type of agriculture. These findings largely amplify, but do not radically alter, the conclusions made in the first IPCC report. They do, however, confirm that the impact of global warming on agriculture may be serious if warming is at the upper end of the range projected by the IPCC Working Group I.

Recent studies have reinforced concern that drought is the area in which climate change poses the greatest risk for agriculture and consequently arid and semi-arid regions are likely to be most vulnerable to climate change.

Other recent studies confirm the IPCC earlier conclusions that climate change may benefit ecological conditions for insect growth and abundance which is likely to have a negative effect on crop, livestock and forest production in some regions.

Research continues to address the relative importance of direct and indirect effects of CO₂, in combination with a rise in temperatures, on future crop production. While some scientists emphasize enhanced photosynthesis and more efficient water use seen in controlled settings, others are skeptical that these benefits will be seen in farmer's fields under changing climate conditions.

The effects on plant growth may result in the maintenance of present-day soil conditions in some regions, as greater soil organic matter and denser ground cover may counter the effects of soil erosion caused by increased rainfall intensities and oxidation rates of organic matter in soils caused by higher temperatures.

Adaptation to climate change by the existing agricultural production system should be possible, and the worldwide systems of agricultural research should be able to provide new crop cultivars that maintain high yields and nutritional quality. However, efforts will be needed to make such developments available to small farmers in developing countries in time to respond to changes in local climatic conditions.

New analyses support the IPCC 1990 Report conclusion that the impacts of climate change on forests could have significant socioeconomic consequences. This is especially important for those countries and regions where economic and social welfare and economic development are highly dependent on the forest sector.

Key uncertainties require continued data collection and research for policy development and decision-making. These include: (1) the extent of managed and natural forests, their spatial and temporal variation and their roles in the global carbon cycle; (2) genetics and physiology of tree species and the relationships among subordinate and competitive species; (3) regional impacts; and, (4) the linkages among the regional impacts, socioeconomic structures, and the thresholds and critical limits where changes take place.

Natural terrestrial ecosystems

Analyses subsequent to those included in the IPCC First Assessment Report (1990) reinforce the major conclusion of that report that natural terrestrial ecosystems could face significant environmental impacts as a result of the global increases in the atmospheric concentration of greenhouse gases and associated climatic changes. In particular, these studies continue to suggest that the rate of these changes will be the major factor in determining the type and degree of impacts with a variety of responses expected for different regions and for different communities within ecosystems. Current climatic projections continue to suggest that the rates of change are likely to be faster than the ability of some component species to respond and that species and ecosystem responses may be sudden, potentially leading to ecosystem destabilization or degradation.

The promotion of heightened public awareness of the general values of natural terrestrial ecosystems is essential to gaining public support for sustaining these ecosystems in a changing climate. Particular emphasis should be placed on involving ecosystem managers and local people in the assessment of the impacts, consequences and response strategies.

One of the major issues regarding the impacts of climate change on terrestrial ecosystems is water availability with recent studies suggesting that while water use efficiency of vegetation could increase in an enriched CO₂ atmosphere, the same amount of water per unit soil area may be necessary because of increased leaf area ratios due to greater biomass produced in that enriched atmosphere.

Projected climate changes are expected to result in an accelerated reduction of tropical forest on the African continent and an encroachment of the Sahel syndrome into the savannas. These changes could worsen the already precarious production systems in the affected regions of Africa, further stressing the associated natural ecosystems and component species. Degradation of wetlands and shallow lakes (e.g., within savanna ecosystems in Africa and within the Great Plains of North America) as a result of projected decreases in rainfall or soil moisture could adversely impact on resident animals and migratory species.

With projected climate change, profound impacts, both beneficial and destructive, can be expected for the distribution and productivity of valuable fisheries and the industries associated with them. The added stresses to freshwater ecosystems as a result of climate change can be expected to reduce species numbers and genetic diversity within freshwater populations in the short term. With warming, a longer growing season could lead to greater fish productivity where temperature is currently a limiting factor.

Uncertainties and gaps in the knowledge base continue to exist in terms of our understanding of the environmental impacts and associated socio-economic consequences of climate changes. National, regional, and global efforts need to cooperatively focus on reducing these deficiencies which primarily exist as a result of the lack of sufficient information and data on: a) fundamental ecological processes; b) the links between climate and atmospheric chemistry on the one hand and the response of natural terrestrial ecosystems and their component species on the other; and c) the links between natural terrestrial ecosystem changes and social and economic welfare under a climate change. In particular, there is a lack of information on the sensitivity of these ecosystems and their component species to climate change, the vulnerability of social and economic systems to ecosystem changes, and thresholds/critical levels for these ecosystems and associated social and economic systems. Existing international programmes such as GEMS and MAB can provide one means of examining these deficiencies.

World oceans and coastal zones: ecological effects

Since the First IPCC Impact Assessment Report, new studies reconfirm that rising sea level is of more concern in low-lying coastal ecosystems than rising water temperatures. However, the combination of sea level and temperature rise, along with changes in precipitation and UV-B radiation, are expected to have strong impacts on marine ecosystems, including redistributions and changes in biotic production.

The impact of sea level rise depends on the total net rise resulting from the relative vertical movements of the land and of the sea. In areas undergoing natural ecstatic uplifting of the land due to tectonic plate movement, glacial rebound, and vulcanism, there will be little relative rise of sea level.

In land areas that are naturally falling as in the southeastern USA, due to tectonic and compaction forces, impacts of sea level rise will be more important. A new study of the Bering Sea indicates that in areas without natural land uplift, there could be important impacts where there is a high density of marine organisms dependent on certain types of on-shore and near-shore marine environments that may be affected by sea level change. Nevertheless, sea level change is of far less consequence in northern areas than are other impacts of climate change to northern ecosystems and to global carbon cycling. These regions are very important in the global carbon cycle and a small temperature rise may cause significant increases in bioproductivity and in carbon flux to the oceans.

Coral organisms grow 1-20 cm/year and reef growth rates as a whole are known to be up to 1.5 cm/year. Not all reefs accumulate at these rates, but most should keep pace with the expected rise in sea level if other factors do not alter growth conditions. Stress on reefs from other variables (storms, sedimentation, disease, rainfall, radiation, turbidity, overfishing, mass mortality in algal grazers, etc.) may prevent some reefs from keeping pace with rising sea level, resulting in changes to nearshore hydrodynamics.

With respect to temperature rise, marine organisms in the tropics live closer to their maximum thermal tolerance than those in more temperate climates. Although a 1-2°C temperature rise would raise the summertime mean temperature to over 30°C over much of the tropical/subtropical region, most migratory organisms are expected to be able to tolerate such a change. Temperature rise may trigger bleaching events in some corals, but it is expected that the other stresses mentioned above will be more important.

Intertidal plants, such as mangroves, can withstand high temperatures, and unless temperature rise affects reproduction, it is unlikely to have any effect. Because mangroves grow best in moderately saline environments, mangroves can probably keep pace with sea level rise in rain-fed humid areas, but may be overstepped and abandoned in more arid areas, particularly if inland retreat is not possible. Thus, future changes in patterns of rain and runoff and of overcutting may be more important than sea level rise. With respect to marshes, new studies indicate that mid-latitude plants seem to tolerate salinity better and are more productive under elevated CO₂.

New findings of WMO/UNEP indicate that UV-B radiation reaching oceanic and coastal zone environments will increase faster than expected when the first Report was written. Since so many marine resources spend all or vulnerable parts of their lives near the water surface, there is a significant threat to some fisheries. The first Report expressed concern about leaching of contaminants during sea level rise, from coastal waste disposal sites. There are also bacteria and viral agents in such sites and in coastal septic sewerage systems which could be increasingly released into coastal waters. There are potential impacts on coastal resources, but the primary

concern is for the humans who consume them and the loss of commerce due to the closure of fish and shellfish areas by health authorities. Lastly, potential changes in storm frequency or intensity could have important ecological consequences to coastal resources.

Hydrology and water resources

Since the publication of the IPCC First Assessment Report, a number of studies on impacts of climate change on hydrology and water resources have been conducted. Unfortunately, there is not yet adequate information on regions affected by aridity and desertification, and an effort should be undertaken to fill that gap. The new studies expanded on the geographic scope of the original surveys, but few new insights were offered on hydrologic sensitivities and vulnerability of existing water resources management systems, while confirming many previous conclusions.

The principle conclusions suggested by the new studies are:

- Significant progress has been made in hydrologic sensitivity analyses in developed countries, yet large gaps exist in the information base regarding the implications of climate change for less developed nations;
- Comparative sensitivity analyses that rely on existing GCMs offer generic insights regarding the physical hydrologic effects and water resources management impacts, but the differences in the outputs of the GCMs coupled with large differences in hydrologic sensitivity analyses makes it difficult to offer region-specific impact assessments.
- Temporal streamflow characteristics in virtually all regions exhibited greater variability and amplification of extremes, with larger flood volumes and peak flows as well as increased low flow episodes and a shift in timing of the seasonal runoff;
- The higher the degree of water control, regulation and management of sectoral water demands, the smaller the anticipated adverse effects of global warming. Conversely, unregulated hydrologic systems are more vulnerable to potential hydrologic alterations;

The principle recommendations are:

- Increased variability of floods and droughts will require a re-examination of engineering design assumptions, operating rules, system optimization, and contingency planning for existing and planned water management systems;

- More studies on hydrologic sensitivity and water resource management vulnerability need to be focused in arid and semi-arid regions and small island states.
- A uniform approach to the climate change hydrologic sensitivity analyses needs to be developed for comparability of results.

Cryosphere

Analyses continue to support the conclusion that projected changes in climate associated with enhanced atmospheric concentrations of greenhouse gases are expected to substantially reduce the areal extent and volume of seasonal snow cover, mountain glaciers, terrestrial ice sheets and frozen ground including permafrost and seasonally frozen ground.

Recent analysis have shed some further light on the potential impacts for these elements of the terrestrial cryosphere.

- Analysis of satellite-derived snow cover data has shown that the extent of northern hemispheric snow to be at record low levels since the middle of 1987 with the largest negative anomalies occurring in the Spring.
- Above normal temperatures throughout much of the Northern Hemisphere in 1989 led to the initiation of extensive active layer detachment slides within permafrost in some regions of the Canadian and Russian Arctic with damming and degradation of water quality in affected streams and further failures initiated.
- Emissions in Arctic regions of methane from hydrates as a result of permafrost degradation may have been underestimated.
- There is some evidence to suggest that glaciers in the Northern Hemisphere polar and subpolar regions are receding at a slower rate than previously suggested with some having advanced in the past 30 years. Although the Southern Hemisphere record is not as detailed, records for several New Zealand glaciers show that these have retreated since the mid-1800s with the suggestion that this has been the result of an increase in temperature and an accompanying decrease in precipitation.

Key uncertainties are associated with understanding fundamental cryological processes, the relationship among these elements (e.g., impacts of changes in snow cover on permafrost and glacier dynamics), the impacts of climate change on these elements of cryosphere, the interdependency of associated ecosystems (e.g., soil erosion and stability changes associated with permafrost degradation) and human systems (e.g., structures, transpor-

tation, transmission lines), and the role of the cryosphere in local, regional and global climate and climate change.

**SECTION IV. TASK 3:
ENERGY AND INDUSTRY RELATED ISSUES**

BY WORKING GROUP III

2. SUMMARY OF SUBTASKS

2.2 The IPCC Technology Characterization Inventory (TCI)

The IPCC Technology Characterization Inventory (TCI) provides an information source of consistent, well-documented technology data for analysis and planning activities to limit greenhouse gas emissions. Special emphasis is given to technologies having potential interest to developing countries and economies in transition. Information from many sources is used to describe technologies in five categories: (1) Primary Energy Production (2) Secondary-Energy Conservation and Processing (3) Energy Transfer (4) End-Use Technologies and (5) Greenhouse Gases Control Technologies.

Because information and data are not sufficiently detailed for design of specific technology installations, addresses for specialists around the world are provided. The data base includes information for energy sources and major regions of the world. Country-specific information can be included as it becomes available from specific applications and analyses.

Phase I consists of a preliminary design of the data base and descriptions of eighteen technologies. These eighteen technologies shown in Table I were submitted to the IPCC for review in February 1992. The Phase II effort began in December 1991. By June 1992, the TCI will include about 90 technologies. Future versions of the data base are expected, including both updated and added technologies.

Table 1: TCI Phase I Technologies

SUPPLY TECHNOLOGY

- Pulverized Coal Steam Generation
- Gas Turbine-Steam injected, inter-cooled (ISTIG)
- Atmospheric Fluidized Bed Combustion
- Diesel Cogeneration
- Solar Thermal Electric-Parabolic trough
- Mass Burning of Municipal Solid Waste
- Efficient Electrical Transformers

ENERGY END-USE TECHNOLOGY

- Electric Motors
- Lighting-Compact fluorescent lighting
- Lighting-Electronic Fluorescent Ballasts
- Alternative Fuelled Vehicles-methanol
- Alternative Fuelled Vehicles-CNG
- Advanced Road Traffic Signalization

MANUFACTURING TECHNOLOGY

- Motors-Industrial electric motors
- High Efficiency Welding Power Supply
- Chemicals-Efficient fertilizer production
- Pulp & Paper-Mechanical dewatering
- Petroleum Refining-Process (Distillation) control systems

2.3 Technological Options for Reducing Methane Emissions

Reducing global anthropogenic methane emissions by about 15-20 percent can halt rising atmospheric concentration of methane. A technological assessment of options for reducing methane emissions from anthropogenic sources (about 60 percent of global methane emissions) has been developed through the United States/Japan Working Group on Methane, which compiled information submitted by IPCC participating countries. Technological options are available for limiting emissions from the major sources, other than flooded rice cultivation and biomass burning. These options may be economically viable at suitable locations in many regions of the world, and represent different levels of technical and capital needs. . . . In many cases, these options provide a range of benefits, including better air quality, better protection of surface and ground-water, enhanced productivity, reduced risk of explosion, and improved availability and use of energy resources. Some of these technologies are already established and proven beneficial in certain markets. Barriers which hinder the further implementation of these options in many countries, especially developing countries include availability of capital, lack of technical information, and conflicting incentive systems. These barriers need to be addressed on a country- and site-specific basis.

2.4 Increasing Electricity End-Use Efficiency

The study address the topic of increasing electricity end-use efficiency by providing an in-depth review of the following: (a) the status of available technologies for increasing electric end-use efficiency; (b) factors that limit the application and widespread deployment of these technologies; and (c) policies that have been implemented to increase the efficiency of electricity end-use.

The conclusions of the report are summarized as follows: a substantial fraction of increased anthropogenic carbon emission over the next several decades is likely to come from electricity generation. Increases in end-use efficiency improvements beyond those expected to occur under current technologies and policies could cut significantly the growth of electricity use and associated growth in projected carbon emissions. Based on experience among industrialized and developing countries concerning the technologies and programmes and policies, significant increases in electricity end-use efficiency are possible. It appears that many of these increases can be achieved in a cost-effective manner. Enhancing adoption of these efficient technologies by developing countries is an essential part of a successful strategy to curtail growth in emissions of greenhouse gases.

2.5 Natural Gas Prospects and Policies

One option for reducing CO₂ emissions is the substitution of natural gas for more carbon-intensive fuels. The demand for gas is growing worldwide and is expected to nearly double by the year 2005. As the starting point for its analysis, the IPCC has reviewed the International Energy Agency's (IEA) natural gas study, *Natural Gas Prospects and Policies* (October 1991). This study provides a comprehensive analysis of demand and supply for natural gas including the institutional framework surrounding the production, transmission and use of natural gas. The study's primary focus is on demand for natural gas in OECD countries, but sources from outside the OECD are extensively treated. The IEA forecasts that demand for natural gas outside OECD will be approximately twice that of OECD by 2005. The study indicates that ample gas resources exist worldwide even with the expected doubling of demand in some of the regions through the year 2005 at prices ranging from \$3 to \$6 per MBtu (in 1990 US\$). However, the study did not address the ability to meet demand after 2005. Intergovernmental agreements to facilitate and maintain competitive markets, access to resources and transmission systems, and commercial contracts on a nondiscriminatory international basis are likely to be required before private capital can be mobilized to back very large, long term gas development in remote parts of the world.

Further IPCC analysis should be devoted particularly to non-OECD countries, greatly increased global regional demand, and supply and demand issues beyond 2005.

2.6 Thematic Assessment of the Road Transport Sector

Because of the importance of the road transport sector, to present and future emissions of greenhouse gases, the Panel decided to carry out a thematic analysis of the sector. The work will concentrate on such measures

as fuel efficiency, alternative transport fuels, emission reduction devices and structural, institutional, and organizational changes. The work is just beginning so no conclusions are available at this time.

2.7 Biomass, Bioenergy and Limitation of Greenhouse Gas Emissions

A review of the use of biomass as a source of energy concludes that bioenergy offers important opportunities to reduce greenhouse gases through displacement of fossil fuels. It is noted that CO₂ emissions from renewed or waste biomass do not add to the overall atmospheric burden of carbon on a life cycle basis. Some biomass combustion technologies are available that, additionally, reduce other greenhouse gases (e.g., CH₄ and N₂O).

Greenhouse gas emissions can be reduced both by sequestration of carbon and production of bioenergy. The following measures should be considered: use of waste biomass as a fuel and production of biomass by intensive but environmentally sound forestry and agriculture practices, consistent with conservation of carbon in forests and soils.

Combustion of biomass can already be competitive with fossil fuels for (1) production of heat or steam and (2) cogeneration of steam and electricity. Environmentally sound production of liquid biofuels should also be considered.

The first part of the report is available for review. The second part of the report dealing with technologies will be available in late 1992 for review.

2.8 World Economic Impacts of Response Measures by Industrialized Countries

Carbon dioxide and carbon taxes in the energy sector have been the focus of several available studies. The economic impacts of such measures to control the greenhouse gas emissions would vary among industrialized countries, because of the difference existing among them in their resource endowments, the relative structure of energy prices, the ability for fuel substitution and the achieved levels of energy efficiency. The studies reviewed to date in this effort indicate that the costs of applying carbon tax measures could reduce GDP growth in industrialized countries. The costs could be reduced if flexible, phased, comprehensive and concerted response strategies were adopted to control greenhouse gases. Further systematic and comprehensive analysis of available studies is needed on this important and complex subject.

The impacts of these measures will not be limited to industrialized economies, but will also affect the economies of developing countries. One general economic study by the World Bank indicates that a change in OECD growth could affect the growth rate of developing countries rather significantly without off-setting programmes. Factors of this economic interdependency include energy prices, balance of trade, developing country revenue, external debt, investment and aid flows.

2.9 Analysis of Factors Affecting Energy Consumption and CO₂ Emissions and Their Regional Sectoral Differences

This assessment deals with factors affecting regional and sectoral differences in energy consumption and related CO₂ emissions. The supporting material contains: (a) analysis of factors affecting total and sectoral CO₂ emissions; (b) regional comparison of changing rates of factors; (c) long run changes in carbon intensity and technology improvements; and (d) non-commercial energy consumption in developing countries. The assessment indicates that such factors as economic development, population growth, energy conservation, changes in industrial structure, fuel switching, and technological advance influence the regional and sectoral patterns of historical energy consumption and CO₂ emissions. Other factors such as climate conditions could be also considered. These factors function differently in different countries and regions.

Analysis of energy consumption and CO₂ emissions would be important to select and plan a suitable set of options for mitigating global warming. The analytical methods reviewed in the assessment underway can be useful tools. Some methods discussed can provide a common analytical framework for countries, even with present limitations on data availability. The analysis will also deepen common understanding of historical and current situations of individual countries.

Future subjects of this interim assessment include: (a) separation of industrial structure changes and energy efficiency improvements in the energy conservation factors; and (b) sectoral analysis of factors affecting energy consumption and CO₂ emissions in developing countries. The analyses discussed in this study could serve as starting points. Further detailed research would be useful on more factors affecting energy consumption, economic cycles and CO₂ emissions in each sector on the basis of results obtained in the work now underway.

2.10 Country Studies

A survey of country studies has been developed in cooperation with UNEP and through review of other sources. The term "country studies" is defined to include any official national study on greenhouse gas emission inventories, impact assessments, and emission mitigation analyses. It includes energy and industry, agriculture, forests and other sectors. Numerous other studies have been undertaken by institutions in various countries which are not reflected in this survey, since they have not been endorsed as official national studies. As of February 1992 more than fifty countries have or plan to initiate some form of country study through internal, bilateral or multilat-

eral support.* In addition, several countries have indicated a wish to participate in country studies, but lack the financial and/or technical resources to carry out such studies.

As yet, a comprehensive methodology for country studies has not been developed, although work is underway in several IPCC working groups and elsewhere to partially address this need. Current efforts include a project supported by UNEP to establish a consistent methodological framework for undertaking cost assessments of greenhouse gas abatement options. The project is being implemented by Riso National Laboratory in Denmark. In addition, draft guidelines have been prepared by Finland and the U.S. All these activities may assist countries in preparing future studies, but there is an urgent need to give a higher priority to these activities.

TASK 4: AGRICULTURE AND FORESTRY RELATED ISSUES

BY WORKING GROUP III

2. AGRICULTURE

2.1 Present and future agricultural GHG emissions

Recent improvements in scientific understanding support the previous findings of the 1990 report, in particular the following.

As far as the net carbon dioxide release from agricultural activities is concerned, forest clearing in the tropical and subtropical areas of the world continue to be the major source. Additionally, the cultivation of virgin land, whether in tropical or temperate agricultural areas, results in gradual carbon losses. Its relative contribution, however to CO₂ concentrations is still to be determined. At the other extreme, long-standing arable soils do not constitute a major net source of CO₂, because their carbon contents reach equilibria which do not change very much unless cropping and management practices are altered.

Projections of future GHG emissions related to land use depend on the initial use, the rate of land conversion, and productivity including cultivation density. If production did not increase, expected population growth and rising food demand would require the area of tropical agriculture to expand by over 60% by the year 2025. It is unlikely this additional land would be

*Argentina, Australia, Austria, Bangladesh, Belgium, Brazil, Canada, China, Congo, Costa Rica, Czechoslovakia, Denmark, Finland, France, Gambia, Germany, India, Italy, Indonesia, Ireland, Japan, Kenya, Democratic Peoples' Republic of Korea, Republic of Korea, Malaysia, Mauritius, Mexico, Mongolia, Morocco, Myanmar, Netherlands, New Zealand, Nigeria, Norway, Pakistan, Philippines, Poland, Romania, Senegal, Seychelles, Sri Lanka, Sweden, Switzerland, Tanzania, Thailand, Turkey, Tuvalu, Uganda, United Kingdom, United States, Venezuela, Vietnam, Zimbabwe.

available. If all the additional land were to come from forest or grassland, it would cause a gradual breakdown of soil organic matter, releasing CO₂.

There may be another effect in that global warming will speed up the decomposition of soil organic matter, thereby releasing additional CO₂ to the atmosphere. Model calculations, assuming no increase in organic residue returns, predict this soil carbon loss to be up to 60 Gtons within about 60 years. This corresponds to a current global CO₂ release from fossil fuel of about 10 years. On the other hand, there are indications that this could be offset by an enhanced plant residue formation both above and below ground, due to the CO₂ fertilization effect.

As for the release of methane, total global and individual source emission estimates remain essentially as presented in the IPCC First Assessment Report (1990), but with some individual source changes. There has been a reevaluation of some sources, particularly rice, and the additional sources such as animal and domestic wastes. A large portion of these emissions comes from liquid waste handling systems. Uncertainties in global and regional emissions remain significant. A detailed analysis of new information on rice suggests annual emissions in the lower end of the 20-150 Tg/year range.

In the absence of mitigation measures, methane emissions are likely to continue to increase from each source as increases in animal products and rice are required in order to feed the world population. Current emissions for animals, rice, and animal wastes could grow by about 40-60%, 50-60% and 30-40% respectively by [the year] 2025.

Unfortunately, the data concerning the release of nitrous oxide from agriculture still cannot be reliably derived. Keeping in mind that the annual increase of N₂O in the atmosphere is 3.0-4.5 Tg of nitrogen as N₂O, and knowing that the release from combustion processes has thus far been overestimated, most of this net increase may be due to anthropogenic nitrogen inputs. About 80 Tg of industrially-fixed nitrogen is presently applied to world agriculture. Taking the upper value of estimates for the conversion of fertilizer nitrogen into N₂O, which is 3.2%, the fertilizer-induced release for 1990 could be calculated as 2.5 Tg of nitrogen as N₂O. Since another 90 Tg of nitrogen or so are fixed by managed leguminous plants, this combination could account for most of the increase of N₂O in the atmosphere.

Large nitrogen surpluses are frequent, especially in intensive agricultural systems. This excess nitrogen is prone to both nitrate leaching and denitrification, although the ratio of N₂ to N₂O formation varies considerably from case to case. However, it should also be borne in mind that not only the unused but virtually the whole nitrogen introduced by mankind into the world ecosystem will sooner or later become denitrified, thus adding to the overall N₂O increase in the atmosphere. The significant unknown is the time scale over which this will occur.

Background assumptions about future food and land demand being the same as above, nitrogen fertilizer consumption may increase by the year 2025 from 80 to more than 120 Tg of nitrogen per year. Without changes in technology, the fertilizer-derived release of nitrous oxide is likely to increase by some 50%.

2.2 Agricultural potentials for mitigation adaptation

In order to reduce the net carbon dioxide release from agriculture, improving the productivity of existing arable land should be given priority over the cultivation of virgin soils. Furthermore, in the less populated areas of the world, marginal farmland could be set aside for either rangeland or forest use.

Reduced soil tillage, improved utilization of organic wastes as amendments of carbon into the soil and crop rotations including forages are agricultural practices which reduce carbon losses and/or sequester additional carbon in soils. Although these practices may sequester several gigatons (Gt) of carbon over a few decades, this represents only a fraction of the release of carbon from fossil fuels over the same period. This is because soils have a finite capacity for accumulating organic matter. Nevertheless, these management practices are essential if soil fertility is to be maintained or enhanced.

As for the control of methane, while investigations are continuing on emission reducing options, the principal approaches remain as reported in IPCC (1990). Opportunities exist to reduce methane from enteric fermentation and animal waste storage, for example, by modifying feeding practices, using productivity enhancing practices and agents, and modifying waste management practices. Emissions reductions of 25 to 75% per unit product in some animal management systems appear feasible. Due to the diversity of animal management systems, including economic and sociocultural factors, the importance of categorizing management systems and matching emission-reducing options to the systems is now being emphasized. Additionally, the implications of reduction options for the emissions from animal waste of other greenhouse gases, including nitrous oxide, are now being addressed.

Methane emissions from rice cultivation may potentially be reduced while maintaining or enhancing productivity. Mitigative practices may include modifying water depth and timing of irrigation, the type, rate, and application method of fertilizer, alternative cultivation technologies, and cultivar selection. Much research is still required in order to realize these opportunities, and therefore a short-term reduction of methane emissions from rice growing cannot be expected. However, over a number of decades, while doubling rice production, an integrated management approach may succeed in reducing methane releases by 20-40%.

Better balanced nitrogen budgets, especially in intensive agriculture, are a key measure for reducing overall nitrous oxide emissions. This should also include a better accounting for the nitrogen from livestock wastes within fertilizer application regimes. Other options include nitrification inhibitors or improved fertilizer formulations and application. However, the most promising way to reduce N₂O losses is an integrated nitrogen-management system which maximizes nitrogen recycling while minimizing fertilizer inputs. This is all the more important since N₂O, due to its long lifetime, will accumulate in the atmosphere, constituting an increasing threat to the ozone layer.

In addition to these mitigation strategies, future efforts of AFOS should assess the ability of agricultural systems to adapt to climate change.

3. FORESTRY

Forests provide mankind with a wide range of economic, social and environmental benefits, but they are increasingly being threatened by unsustainable forest management practices, air pollution, and climate change. Concerted action needs to be taken at national and international levels to protect the world's forests. Action will be successful only if it takes into account the interdependence of the economic, social and cultural factors that bear on the management of forests.

3.1 Status of forests

It is difficult to determine the present extent of tropical forest cover. Recent estimates on a country basis indicate that there are approximately 1.9 billion hectares of tropical forests.

One concern has been given particular attention since the IPCC (1990) is the rate of deforestation globally and in individual countries. The FAO estimated rates of global deforestation for the 1980s in closed forests (about 14 million hectares/year) and in closed and open forests (about 17 million hectares/year) are much higher than for the late 1970s, by 90% and 50%, respectively. Calculations by other authoritative sources show significantly lower figures in the order of about 10 million hectares.

Approximately 770 million hectares of forests belong to the temperate zones with an estimated carbon storage of 25 Gt in biomass excluding soils. Forest area in boreal zones amounts to about 920 million hectares, storing 150-190 Gt of carbon in biomass including soils. In addition a considerable amount of carbon is stored in forest soils and peatlands, especially in boreal zones.

3.2 Forestry options

The following four options were identified:

Slowing currently ongoing deforestation and forest degradation

For an accurate assessment of cost effectiveness, it would be necessary to quantify the reduction of the amount of carbon released to the atmosphere. So far, only preliminary estimates can be given. Nevertheless, it seems evident that first priority should be given to this option, thus maintaining already existing biomass in natural as well as in managed forests. In tropical regions, it is necessary to involve local people in sustainable silvicultural practices. In temperate and boreal zones, this refers especially to the new type of forest decline attributed to man-made air pollution, logging, and to the potential effects of climate change itself. Slowing deforestation and forest degradation bears a significant potential to keep carbon stored in biomass, retards desertification and is the requirement for further action.

Increasing forest biomass

There is generally a significant potential for increasing biomass in forests, especially in young, understocked, overlogged and/or misused forests. However, the costs and time-frame are uncertain.

Improved use of wood

The use of wood for long-lived products provides benefits in terms of carbon storage as well as sustainable forest management. Industrialised countries have possibilities for improved use of wood, such as the recycling of paper and paperboard, and the replacement of more fossil energy intensive raw-materials by wood. The use of wood as a source of energy offers important opportunities for reducing GHG emissions by substituting fossil fuels (as described in the EIS report).

Afforestation

The potential for afforestation in boreal, temperate and tropical biomes is uncertain. However, the current estimates for afforestation are 50-150 million hectares in boreal, 50-125 hectares in temperate and 400-750 million hectares in tropical zones (200-300 million hectares in dry tropical areas). For tropical zones, the land potentially available will be less than the amount physically capable of afforestation because the ultimate decisions on land use are based on many other factors. For the boreal zones, the potential to increase the forest area is limited because not all non-forested land is environmentally capable of supporting forest ecosystems.

At present, plantations account for most of the afforestation in temperate zones. Preliminary assessments of gross costs of afforestation have recently become available and range from U.S.\$30 - U.S.\$60 per ton of carbon in boreal and temperate zones and U.S.\$10 - U.S.\$30 per ton of carbon in the tropical zone. However, it is uncertain how much carbon could be sequestered at such costs.

3. Noordwijk Request

The Noordwijk Conference on "Atmospheric Pollution and Climate Change" in November 1989 established the target of a net global increase in forest area of 12 million hectare a year by the beginning of the next century. The Bangkok Workshop (1991) concluded that the prospect of attaining the target was very limited, and that the net rate of forest loss would be slowed or reversed over a longer period of time. However, the option of afforestation would still be important and better data [would] need to be developed to assess the potential.

