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<td>Raghubanshi, A. S.; Singh, J. S.</td>
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Future Climatic Change: Causes And Consequences

By

A S Raghubanshi
&
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Future Climatic Change: Causes and Consequences

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Introduction:
Although man has been altering the environment for at least two million years, it is only recently that the influence has approached global proportions with almost inevitable changes in the climate. Increases in carbon dioxide and other greenhouse gases, concerns for climatic change, the appearance of the antarctic ozone hole and worldwide depletion of ozone shield, tropical deforestation, and a host of other changes in our environment have captured the attention of scientists, the public, and policy-makers (CGC, 1988). Because of the great social, economic, and scientific importance of anthropogenic climatic changes, they are being intensively studied in order to derive predictive models (Lachenbruch and Marshall, 1986).

The atmospheric concentrations of the greenhouse gases, especially CO$_2$, CH$_4$ and the chlorofluorohydrocarbons (CFCs) are increasing, with the prospect that the radiative consequences by 2050 will be the equivalent of a doubling of CO$_2$ from pre-industrial concentrations. Levels of CO$_2$ in the atmosphere have already increased by some 25 per cent since the Industrial Revolution, they are expected to increase a further 30 per cent in the next 50 years. Although the increase in global carbon dioxide caused by the burning of the fossil fuels appears to be the largest anthropogenic cause of
world climatic change, it is by no means the only one (Harrington, 1987). It has been estimated that the enhanced combined climatic warming caused by greenhouse gases other than CO₂, especially CH₄, N₂O, CFC₁₃ and CF₂Cl₂ will match that of CO₂ in coming decades. Senum and Gaffrey (1985) attribute 30 per cent of the current greenhouse warming to the yearly rate of increase of methane. Effects of greenhouse gases other than carbon dioxide is large because these gases absorb far-infrared radiation in spectral band where there are gaps in the CO₂ and H₂O spectra. Carbon dioxide accounts for only 12 per cent of the annual temperature rise due to anthropogenic gaseous pollutants (Harrington, 1987). Table 1 shows the ambient concentrations and annual increase in the concentration and greenhouse warming by CO₂, CH₄, N₂O, CF₂Cl₂ and CFC₁₃.

The Greenhouse effect:

The atmosphere that surrounds the Earth plays a critical role in maintaining even temperatures on the Earth's surface. Short-wave radiation from the sun reaches the Earth's surface unhindered but the outgoing long-wave radiation is partially trapped or retained by the atmosphere. Thus like the glass in the greenhouse, the atmosphere absorbs some of the long wave radiation emitted by the Earth, and radiates energy back at the earth. This downward flux warms the Earth and is known as greenhouse radiation. If the atmosphere were not present, temperatures on Earth would be much lower than they are, about -20°C. Increased greenhouse gases produced
by human activity change the atmosphere's structure and absorb more of the Earth's radiation and return more of it back to the Earth. This energy, which would otherwise escape harmlessly into space, is already increasing the Earth's surface temperature and is the main cause of climate change.

Current predictions (Manabe and Stouffer, 1980; Manabe and Wetherald, 1975; Hansen et al., 1984) indicate a steady state increase in global temperatures of 1.5 to 4.5 °C by the year 2030 and a 6 to 10°C increase between 50 and 60°N over the continents (Manabe and Wetherald, 1986; Mitchell, 1983). Equatorial temperatures are expected to remain within 2.0 °C of their present values. This difference arises because of the fact that at high latitudes the water vapor content is low and CO₂ is the main absorber of terrestrial radiation and near the equator a large fraction of the outgoing terrestrial radiation is absorbed by water vapor, thereby decreasing the effect of CO₂. Thus in temperate zones, winters would tend to be shorter and warmer, summers longer and hotter.

A projection of computed temperature trends to the 22nd century due to increasing levels of CO₂ is shown by Hansen et al. (1981). According to these calculations, the world climate will warm appreciably even without growth in the consumption of fossil fuels. Towards the end of 20th century oil and gas will be significantly depleted (Royal Society, 1974), but coal supplies will be ample. The supply of coal should last well into the 22nd century. Harrington (1987) considers that fear of nuclear power by the public
will likely lead to continued use of coal and, therefore, to a
temperature increase less than under fast growth in fossil fuel use
but more than under the conditions of coal phaseout beginning year
2020. In the latter situation earth's mean temperature would be
equivalent to that experienced during the age of dinosaurs 65 Ma
ago.

The projected increase in temperature would cause widespread
changes in precipitation pattern (Hansen et al., 1981; Kellog and
Schware, 1981). It is suggested that there will be an increase
in precipitation over India, and decrease in central and Southcentral
USA and over much of Europe and Russia (Wigley et al., 1980). Summer
dryness may become more frequent over the continents at middle
latitude in the Northern Hemisphere. Some models suggest a 40 per
cent decrease in rainfall in American Great Plains by the year 2040.
In some areas, increased temperature could exacerbate regional
drying (Manabe et al., 1981).

Sea-level rise

A rise in sea level resulting from thermal expansion of sea
water and melting of glaciers and polar icecaps has been widely
discussed (Hansen et al., 1981; Hoffman et al., 1983; NRC, 1983). Estimates vary from a rise of 70 cm over next century (NRC, 1983) to
that between 144 and 217 cm by 2100 (Hoffman et al., 1983). However,
if the western icecap melted, rises upto 5-6 m might occur over the
next several hundred years (Hansen et al., 1981; NRC, 1983). This
increase in sea level rise will be more than enough to flood huge
areas of unprotected coastal land. Nearly one-third of all human beings live within 60 km of a coastline. A rise in sea level even half a metre could therefore have profound effects on habitation patterns, causing many people to move and many of the world's most important cities and parts to come under threat of flood. Adapting to rising sea levels will be easier for rich countries, which are likely to be able to afford elaborate sea defences, than for poor ones such as Bangladesh. Fig. 1 shows how far the sea would invade Bangladesh due to rising sea level.

**Major sources of greenhouse gases:**

Large amounts of many biologically produced trace gases are exchanged annually between the atmosphere and biosphere, and many of these are now increasing in flux or concentration or both as a consequence of human activities. Understanding and proper quantification of the major sources of the greenhouse gases will increase our capability to control emissions of these gases.

**$\text{CO}_2$**

Quantities of carbon dioxide are increasing in the atmosphere because of industrialization and land management activities (Haughton et al., 1983). It has increased from a concentration of less than 280 ppm a few hundred years ago to present values of about 345 ppm (Neftel et al., 1985). The concentration may reach 600 ppm by the end of next century. The principal cause of the increase in atmospheric $\text{CO}_2$ in recent years has been the combustion of fossil fuels. Bolin (1977) has shown that destruction of tropical forests releases as much
CO$_2$ into atmosphere as industrial processes. Though the figures are very uncertain, Detwiler and Hall (1988) have tried to balance a budget for fluxes of carbon for the year 1980 (Table 2).

CH$_4$

After carbon dioxide, methane is the second important greenhouse gas (Stauffer et al., 1988). Methane is increasing in the atmosphere by about 0.8 per cent per year (Thompson and Cicerone, 1986). The main cause of increasing concentrations is the growth of methane sources, although decreasing levels of CH$^-$ (caused by increasing concentration of CH$_4$ itself and carbon monoxide) could also contribute (Thompson and Cicerone, 1986). Methane is produced by specialized anaerobic bacteria that couple the oxidation of reduced compounds (principally hydrogen and acetone) to the reduction of carbon dioxide to methane. Its sources include enteric fermentation in animals and termites (Zimmerman et al., 1982; Fraser et al., 1986), and decay in rice paddy fields, swamps, freshwater sediments, tundras, and terrestrial debris on the continental shelves. The principal sink is the reaction between CH$_4$ and the hydroxyl ion (OH$^-$). Recent increases in atmospheric CH$_4$ concentration (Black et al., 1982; Neftel et al., 1985) partly appear to be due to the removal of CH$^-$ from the atmosphere by the carbon monoxide (CO) emitted in industrial processes, fires, and automobile exhausts (Khalil and Rasmussen, 1984).

Lowe et al. (1988) estimate that almost a third of total methane flux comes from fossil fuel. Recent analysis suggests that the extensive, organic rich arctic and boreal wetlands are especially important sources
of methane; they account for about half of total emissions from natural wetlands worldwide (Matthews and Fung, 1987). Although these estimates are very uncertain, agricultural sources are known to be increasing: both the area under rice cultivation, and the cattle population have grown steadily with human population, doubling in the past 40-50 years. The coal mining source is probably not growing significantly; however the natural-gas source could be, although to date it has not been considered to be significant cause of increasing atmospheric CH₄.

The steady growth in CH₄ concentrations makes an important direct contribution to the atmospheric greenhouse effect (Matthews and Fung, 1987) because each incremental molecule of CH₄ is about 20 times more effective than each additional molecule of CO₂, partially compensating for the 100-fold larger yearly increase in numbers of atmospheric molecules of CO₂ than for CH₄ (Ramnathan et al., 1985; Black and Rowland, 1988). An increase in H₂O in atmosphere also contributes to an enhanced greenhouse trapping of infrared radiation as an indirect consequence of the CH₄ increase (Black and Rowland, 1988).

H₂O

Nitrous oxide (N₂O) is a relatively stable gas that is present in the atmosphere at concentrations around 300 ppbv; its concentration is now increasing at 0.2 per cent per year globally (Weiss, 1981; Khalil and Rasmussen, 1983; Rasmussen and Khalil, 1986).
While denitrification has been considered the major source of $\text{N}_2\text{O}$ in soils and waters (CAST, 1976; Delwiche, 1981; Payne, 1981), it is now recognised that nitrification may also contribute to $\text{N}_2\text{O}$ emissions (Bremner and Blackmer, 1981). Nitrous oxide also can be formed by chemical reactions when $\left[\text{NO}_2^+\right]$ or $\text{NH}_2\text{OH}$ are decomposed in acid soils, producing small amounts of $\text{N}_2\text{O}$ (Corbet, 1935; Arnold, 1954; Nelson and Bremner, 1970; Bremner and Blackmer, 1980; Nelson, 1982), but these processes likely contribute relatively little to $\text{N}_2\text{O}$ production in soils as compared to nitrification and denitrification.

Human activities associated with fertilization of agricultural lands and combustion are believed to be the major cause of the increased $\text{N}_2\text{O}$ (Dickinson and Cicerone, 1986), but emissions from natural systems (Bowden, 1986) and their alteration by land clearing (Bowden and Börmann, 1986; Keller et al., 1986) are relatively poorly known. Tropical ecosystems play a central role in the global cycle of $\text{N}_2\text{O}$ (Crutzen et al., 1985; Mc Elroy and Wofsy, 1986; Rosswall and Paustian, 1984). Recent studies (Keller et al., 1983, 1986) suggest that tropical soils account for approximately one half of the present global source of nitrous oxide, and perhaps three fourth of the preindustrial source (Hao et al., 1987). Land clearing is an increasingly important factor in tropical ecosystem dynamics, and can lead to significant changes in the nitrous oxide flux.

Nitrous oxide is a greenhouse gas, and its increasing concentrations are expected to contribute a small amount towards global warming in the next 50 years. Additionally, $\text{N}_2\text{O}$ oxidizes to nitric oxide in the stratosphere and stratospheric nitric oxide reacts with ozone there.
Increasing concentrations of nitrous oxide may thus make a small contribution toward the breakdown of the stratospheric ozone layer.

**Freons**

The use of freons (CF₂Cl₂ and CFC₁₃) as aerosol propellants has been sharply curtailed in the developed countries due to destructive action of the halogens on ozone in the stratosphere. The Montreal Protocol on substances that deplete ozone layer is an agreement to reduce production and emissions of CFCs (motivated primarily by the need to protect the Earth's ozone layer). The possible effects of CFCs on global climate were noted as an additional cause for concern (Wigley, 1988). Emission of CFCs into atmosphere by anthropogenic usage has modified the long-wave radiation budget of the atmosphere by about 0.1 per cent. The 10.8-μm band of CFC-12 is situated in the thermal window of the atmosphere and hence has a powerful greenhouse effect (Evans, 1988). The Montreal protocol reduces the 1986-2030 warming commitment attributable to CFCs by a factor of three to seven, but high CFC concentration (up to four times of present levels of CFC-12) would still occur eventually unless further restrictions are imposed (Wigley, 1988).

**Impact of Climatic Change on Biota:**

Several authors have independently reviewed the significance of future climate change on species survival (Ford, 1982; Norse and McManius, 1980; Wilcox, 1980; Brubaker, 1986). Models of the earth's climatic system are not yet sufficiently reliable to predict exactly how a given change in climate will affect ecosystem structure and functioning. At present we can only give an indication what might happen when expected warming will occur.
Profound changes in response to global warming are suggested in the distribution of major biomes, particularly those of north temperate and boreal regions (Emanuel et al., 1985). Natural ecosystems would be disrupted, with grasslands and deserts expanding in area, and forested areas growing smaller. In the event of several hundred kilometer poleward shift in temperate belts during the next century, localised populations currently living near their maximum thermal tolerance levels would have to shift northward at a rate of several kilometers per year to avoid being left behind in area too warm for survival (Peters and Darling, 1985). Dispersal rates are crucial to species ability to colonize suitable habitats. Species having slow migration rates or experiencing geographical barriers may not survive and become extinct. Some species, such as plants propagated by spores or dust seeds, may be able to assume this rate (Pering, 1965), but many species would not disperse fast enough to escape the expected climatic change without human assistance (Peters and Darling, 1985).

A direct relationship between fragmentation of ecosystem and many of global changes that have been detected in last few decades seems undeniable (CGC, 1988). Fragmentation of habitat will result in fewer pathways for species migration towards favourable habitat. In all cases of major fragmentation of ecosystem, changes in species diversity and composition are found (Wilson, 1988). Many tropical deep forest and temperate chapparal birds are shown to be highly sedentary because
they do not cross even a very small strip of cleared habitats (Diamond, 1975; 1988).

Given the low rates of plant dispersal, vegetation would not be able to change its geographical distribution as fast as the changes in suitable habitat (CGC, 1988). As a result, there would be lags of decades in adjustment of ecological systems to rapidly changing climatic conditions. CGC (1988) concludes that lags in the match between climate and vegetation will become apparent in the mid-continents long before doubling of carbon dioxide has occurred.

Quaternary palaeorecords show that species do not react en bloc to the climatic change but have responded to change individualistically (Coope, 1979; Davis, 1981). Differences in rate of migration will dissociate communities into their component species. The resulting new combinations of vegetation, climate, and soil can result in altered spatial patterns of such fundamental processes as net primary production (Pastor and Post, 1988). More subtle, but still important processes such as evolved host-pathogen relationships may also be disrupted by the stress of new conditions, resulting in increased frequency of epidemics (Leonard and Fray, 1986).

Rigid associations with a particular latitude, for instance photoperiodic dependence, would make a species a likely candidate for extinction. For example, the endomychid beetle, *Stenofersus rotundus*, in Panama is programmed, mainly through its response to day-length, to terminate diapause in April, at the beginning of
the rainy season (Wolda and Denlinger, 1984). Without changes the species could not live in places where the timing of response to day-length and the beginning of the rainy season did not coincide (Wolda, 1987).

Estimates of vegetation changes in Canada show that due to effect of global warming, the moist and wet boreal forest will be expected to move northward and will be replaced on its southern flank by cool temperate forest. In central Canada, except in the far north, large tracts of the boreal forests will be replaced by cool temperate steppe (Harrington, 1987).

Peters and Darling (1985) have shown that small ecological reserves may be especially vulnerable to the effects of climatic change. A likely result will be the extinction of species that such reserves were established to preserve. While discussing the effect of global warming on natural reserve species, Peters and Darling (1985) identified nine types of species and communities which may be particularly affected by warming trends over the next hundred years. These include (i) peripheral populations located near the edge of a species range, (ii) geographically localised species such as island species, (iii) genetically impoverished species having very small populations and ecotypes, (iv) specialized species requiring narrow range of environmental conditions, (v) poor dispersers, (vi) annuals, (vii) montane and alpine communities, (viii) arctic communities and (ix) coastal communities. Characteristics such as large population
size, broad geographic distribution and high dispersal potential should help protect species and higher taxa from extinction. Paleorecords show that large body size appears to be a disadvantage, at least for terrestrial animals. No tetrapod greater than 10 kg survived the late Cretaceous (Padian and Clements, 1985).

Survival of specialist species may be strongly dependent on a single host. A loss or departure of the host due to climatic change will certainly lead to destruction of the specialized species. For example, in fig wasps, whose reproduction is closely tied to the plant in which they hatch, each of the 750 species can grow only on its own species of fig (Kjellberg et al., 1987). Similarly, Everglades kite (Rostrhamus sociabilis) depends on the apple snail (Pomacea caliginosa) for its food. The snails are themselves localised in distribution, and a decrease in their abundance due to drying of the Everglades has threatened the kite with extinction in the United States (Bent, 1961).

Elevated ambient temperatures may affect land bird fauna through the negative response of nestlings to elevated temperatures (Murphy, 1985; Tomback and Murphy, 1981; Barrett and Runde, 1980; Salzman, 1982). Possible effects of elevated sea temperature on marine flora and fauna can be surmised by taking examples from El Nino events. Temperature controls the sea water density and is related to nutrient concentrations, for example, a strong negative correlation exists between temperature
and nitrate, there are negligible amounts of nitrate above 15°C (Jackson, 1977, 1983). Tegener and Dayton (1987) observed mass mortality in sea-urchins during the periods of high temperature. The severe El Nino of 1982/83 caused extensive damage to the fishing industry and to the sea birds and other organisms (Barber and Chavez, 1983; Feldman, Clark and Halpern, 1984; Schreiber and Schreiber, 1984; Glantz, 1985; Jordan, 1985). Extensive coral mortality occurred all over the eastern pacific (Glynn, 1983, 1984). As a result of nutrient depletion caused by elevated temperatures Macrocystis canopies were reduced and considerable mortality and reduced growth rates occurred in kelp forest communities. During the 1982/83 El Nino event in Chile, the northern populations of the alga Durvillea disappeared and have not yet recolonized (Tomicic, 1985). The kelp, Laminaria japonica, is grown extensively in warm waters (Tseng, 1981) and their sporophytes are temperature sensitive and probably near the limit of the temperatures in which they can survive. An increase in water temperature of only a few degree could eliminate the entire population of this alga.

Available information suggests that the predicted rates of sea level rise are near the upper bound of possible rates of intertidal marsh growth (Bormann et al, 1984). Consequently, sea level rise in the next century is likely to drown many if not all salt marsh systems except in areas where the land is rising and reducing the rate of relative sea level change (CGC, 1988).

If predictions of sea level rise are correct, coastal habitats, such as salt marshes and islets used by nestling birds, may be
inundated or eroded. Salt marshes and estuaries are very important for many birds and fishes as a breeding ground. Any destruction of these areas will lead to extinction of many of these species. Freshwater lowlands along the coast are likely to suffer from the intrusion of salt water. The cypress trees of the US Gulf Coast, for example, do not tolerate salt water, yet they grow only slightly above sea level (Titus et al, 1984).

Island species are one of the most threatened communities as latitudinal migration of these species are limited (Peters and Darling, 1985). If latitudinal migration required by them exceeds the size of the island, a climate change would leave little alternative but extinction.

Wide spread change in rainfall pattern will also affect species survival. Breeding success in many birds may strongly depend on rainfall intensity as shown by Sterna birundo in Germany (Becker and Finck, 1985). The same is true for birds in tropical dry forests in Puerto Rico (Faaborg, Arendt and Kaiser, 1984). Drought in the interior of Australia is shown to strongly reduce the number of suitable rabbit warrents and number of rabbits (Mayers and Parker, 1975). Similarly red kangaroos, Megaleia rufa, are greatly reduced in numbers by a long drought (Newsome, Stephens and Shipway, 1967). In relatively dry years the size of butterfly populations may be severely reduced (Shapiro, 1979; Pollard, 1982). Thus the changing interannual and intraseasonal patterns will undoubtedly affect many floral and faunal components. It is important to collect data on distribution ranges and on responses of as many important species as possible through careful survey and experimentation.
CO₂-fertilization:

Because carbon dioxide is a natural fertilizer, plants will grow faster and larger in higher carbon dioxide world. If carbon dioxide levels double — the yields of many crops, and also of weeds, could increase by an average of about a third. Response to elevated carbon dioxide depends on how a particular crop photosynthesizes: C₃ plants respond well and C₄ plants, much less so. Of the world’s 20 major food crops, 16 are C₃ plants. The other four — maize, sorghum, millet and sugarcane — are C₄ plants, whose yields would not be expected to increase greatly. Unfortunately, three of these are the staple foods of most of the sub-Saharan Africa, where food is already in short supply (UNEP, 1987). While warmer temperatures speed crop growth, they do not necessarily lead to higher yields: muggy conditions, for example, provide ideal breeding grounds for pests and diseases. Because agriculture is generally well adapted to existing climatic conditions, any major change is likely to prove disruptive rather than beneficial. This would be particularly true where crops are farmed on marginal land. There are many questions regarding the functioning of the ecosystems. Would CO₂-fertilization change C/N of biomass which will ultimately affect decomposition and nutrient release patterns? Would plant-water relations change? If photosynthesis increases due to increase in CO₂, would not respiration also increase due to increased temperatures? etc.

Future Initiatives:

International action is urgently required to minimize future greenhouse warming. Because it takes several years for human actions
to produce any effect on the structure of the atmosphere, a start has to be made now. The longer the delay in identifying and implementing the preventive policies, the more extreme the policies imposed to stay the climatic change within prudent bounds will have to be. Even though major uncertainties remain in predicting changes in precipitation and temperature patterns, and even though ecosystem responses are imperfectly known, scientists and policy-makers are advised to explore alternative courses of action. Major national and international initiatives - based on the best available science and policy analysis - should become a top priority for governments and citizens. During 1985, scientists from twenty-nine developed and developing countries met in Villach, Austria, to assess the role of increased carbon dioxide and other radiatively active constituents of the atmosphere on climate variations and associated impacts (Anonymous, 1986). The conference suggested that increased support should go for research, with special emphasis on improved modelling of the ocean, cloud-radiation interactions and land surface processes; and that a major public information effort should be launched. International Council of Scientific Unions (ICSU) has initiated the planning phase of the International Geosphere-Biosphere Programme (IGBP). The IGBP otherwise known as the study of global change, is the most ambitious and probably the most important cooperative scientific endeavour that has ever been launched. The objective of the IGBP is to develop the scientific understanding needed to anticipate future changes in the earth system. Such predictive information provides the foundation for decision makers to develop policies that respond to global change.
There appear to be five possible solutions to the greenhouse problem (UNEP, 1987):

(i) reduce the rate at which fossil fuels are burnt and other greenhouse gases produced;
(ii) check destruction of tropical forests;
(iii) dispose of the greenhouse gases as they are produced elsewhere than in atmosphere;
(iv) recover the greenhouse gases already in the atmosphere and dispose of them elsewhere; and
(v) accept the changing climate and adapt to it.

Only first and last and partly second, solutions appear economically feasible. Carbon dioxide, for example, could be filtered from power station effluents, converted in some other chemical form, and dumped on the ocean floor. But the cost would be enormous.

Carbon dioxide which is already in the atmosphere could, in theory be mopped up by planting more trees on the Earth which would convert carbon dioxide in the atmosphere into woody tissue. According to one recent estimate, we would have to plant 7 million square kilometers of trees to absorb 5 billion tons of carbon per year (Booth, 1988). This is an area roughly equal to all the tropical forest (but not woodland) that has been cleared since man took up agriculture some 10,000 years ago and approximately the size of Australia. In another estimate, Richard Grantham (pers. comm.) suggests that 8 million square kilometers area of new woodland will be required to compensate for the present rate of CO₂ increase. This is approximately the size of the Sahara desert. The net effect of greening
the Sahara, if done properly, would be a negative contribution to global warming. In spite of this optimism, however, successful planting of the Sahara can not be a complete solution to the global greenhouse problem with our present society and population. Reforestation would only be one of several tools for mitigating the greenhouse effect. And indeed, without stopping or slowing the deforestation that is consuming millions of hectares of tropical forests every year, talking about reforestation seems out of touch with reality (Booth, 1988).

The most important and promising way to combat with increasing greenhouse gases is to reduce overall energy consumption and a search for cleaner energy sources. In principle the nuclear energy is one of the possible solutions for developing countries. After a long and wide debate, however, accompanied by applications and accidents in several nations, the nuclear energy has fallen into disfavour and probably will not be able to resume its advantages for many years (Spinrad, 1988). Nevertheless, a huge amount of energy will be needed in any greenhouse correction project and nuclear as well as solar, wind and hydrogen power should be considered (Nisbet, 1988).

Stimulating oceanic photosynthesis to recover the greenhouse gases already in the atmosphere is a possibility because addition of certain chemicals (nitrate, phosphate and iron) is shown to promote growth of marine primary producer, sometimes strikingly augmenting primary production within a few hours (Martin and Fitzwater, 1988; Glover et al., 1988; Wainright, 1987). Oceanic stimulation has
an economic advantage over the other approaches in ease of implementation. One route would be to bring mineral rich deep water to the surface by pumping or promoting upwelling; the latter might be powered by thermo-electric generation. Alternatively, nutrients could be added to the sea (Richard Grantham, pers. comm.). Nutrient additions could lead to eutrophication which is already troublesome in some bays due to domestic and industrial waste. It must be monitored in any such undertaking.

Another suggestion for recovery of the carbon dioxide from the atmosphere manufacturing of non-biodegradable polymers (Richard Grantham, pers. comm.). The new product could be used in construction and in industrial products. This approach is quite efficient and will require a cube of polymer of 5.84 km on a side (the size of the one of the biggest icebergs) to remove entire industrial-age atmospheric excess of CO$_2$. Thus storage of the product, even if none went into construction, does not appear to be a serious problem because of the relatively small volume of polymer required.

To conclude, only a global solution to the problem of greenhouse warming of our planet will work and it must be developed in spite of the many uncertainties and difficulties.


Table 1. Ambient concentrations and annual increases in greenhouse gases (Harrington, 1987).

<table>
<thead>
<tr>
<th>Greenhouse gas</th>
<th>Present ambient concentration</th>
<th>Yearly rate of increase (%)</th>
<th>Increased temperature (mK/year)</th>
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<tbody>
<tr>
<td>CO₂</td>
<td>330 ppm</td>
<td>0.3</td>
<td>2.4</td>
</tr>
<tr>
<td>CH₄</td>
<td>1.6 ppm</td>
<td>1.7</td>
<td>6.2</td>
</tr>
<tr>
<td>N₂O</td>
<td>335 ppb</td>
<td>0.4</td>
<td>3.5</td>
</tr>
<tr>
<td>CF₂Cl₂</td>
<td>300 ppt</td>
<td>9</td>
<td>(4.9)</td>
</tr>
<tr>
<td>CFCl₃</td>
<td>190 ppt</td>
<td>10</td>
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Table 2: Balancing the global budget for carbon, 1980 (Detwiler and Hall, 1988).

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<th>Released</th>
<th>Flux (x10^15 g of carbon per year)</th>
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<tr>
<td></td>
<td>Extreme</td>
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<tr>
<td>Fossil fuel combustion; cement production</td>
<td>4.8</td>
</tr>
<tr>
<td>Tropical forest clearing</td>
<td>0.4</td>
</tr>
<tr>
<td>Nontropical forest clearing</td>
<td>-0.1</td>
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<tr>
<td>Accounted for</td>
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</tr>
<tr>
<td>Atmospheric increase</td>
<td>-2.9</td>
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<tr>
<td>Ocean uptake</td>
<td>-2.5</td>
</tr>
<tr>
<td>Missing</td>
<td>-0.3</td>
</tr>
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*A minus indicates the need for a source of the size shown; a plus, the need for a sink.*
Fig. 1. Maps showing how far the sea would invade Bangladesh with a 50 cm rise (top) and a 2.0-2.5 m rise (bottom) (UNEP, 1987)