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Science and the Climate Convention

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The scientific facts concerning the changes in the composition of the atmosphere that are leading to global warming are briefly presented. This greenhouse effect could be slowed or stopped if action is taken to curb emissions of greenhouse gases or enhance the "sinks" of these gases. The paper also addresses the response of the international community to this problem. Concern over global warming led to a landmark international agreement to work towards preventing global warming. This agreement is the Framework Convention on Climate Change; it was negotiated at the United Nations Conferences on Environment and Development in Rio de Janeiro in June 1992. Government policies that could prevent climate change are discussed.

THE SCIENTIFIC EVIDENCE

Although Arrhenius[1] pointed out some 100 years ago that the emission of carbon dioxide (CO_2) from fossil fuel burning would result in warming of the earth (through the "greenhouse effect") the issue remained academic until the middle of the 20th century.

Experimental evidence established after 1950 proves that the composition of the atmosphere has been changing since the dawn of the industrial age and that the pace of change is quickening (see table 1).

The gases that are most destructive to our atmosphere are CO_2, chlorofluorocarbons (including CFC-11, and CFC-12), methane (CH_4), and nitrous oxide (N_2O). The destructiveness of these gases depends on their lifetime in the atmosphere and their indirect effects (i.e., interactions with other gases and water vapor) and is rated by an indicator called global warming potential (GWP). Figure 1 shows the contribution of each of these gases to the greenhouse effect. Figure 2 shows the relative destructiveness of a molecule of CH_4 and CFC-11 to a molecule of CO_2.

As the climate warms, feedback (changes in water vapor, sea ice, clouds

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Table 1: Greenhouse gases in the atmosphere.

Greenhouse gas	Preindustrial *ppm*	Present *ppm*	Current rate of change *annual percent*	Lifetime *years*	Anthropogenic emissions annually *gigatons*
CO_2	280	353	0.5	50–200	6.0±0.5 of C[a] 1.6±1.0 of C[b]
CH_4	8	1.72	0.9	10	28,000–37,000
CFC-11	0	0.28	4	65	350
CFC-12	0	0.484	4	130	450
N_2O	288	310,000	0.25	150	3,000–4,500 of N

a. Fossil-fuel burning in 1989 and 1990; the burning of the Kuwait oil wells contributed 65 gigatons or one percent of the total carbon emissions (with an uncertainty of 50 percent).
b. Deforestation.

and the oceans) amplifies or reduces the warming. The best tools we have for modeling the climate system are three-dimensional mathematical models known as general circulation models (GCMs).[2] In their current state, these models are fairly crude and they produce considerable uncertainties in predictions of climate change.

The best available information on global climate change comes from the Intergovernmental Panel on Climate Change Scientific Assessment (IPCC) sponsored jointly by the World Meteorological Organization (WHO) and the United Nations Environment Program (UNEP). Several hundred scientists from 25 countries have participated. An additional 200 scientists have been involved in peer review. In 1990, IPCC published a report[2] that is an authoritative statement of the views of the international scientific community at this time. It was followed by a supplement[3] in 1992 which updated, but did not substantially change, the conclusions of the original report. The major conclusions of the 1992 report are:

- Human activities are substantially increasing the atmospheric concentration of the greenhouse gases;
- Modelling and empirical studies indicate that doubling the CO_2 concentration would increase the global mean surface temperature by 1.5 to 4.5°C;

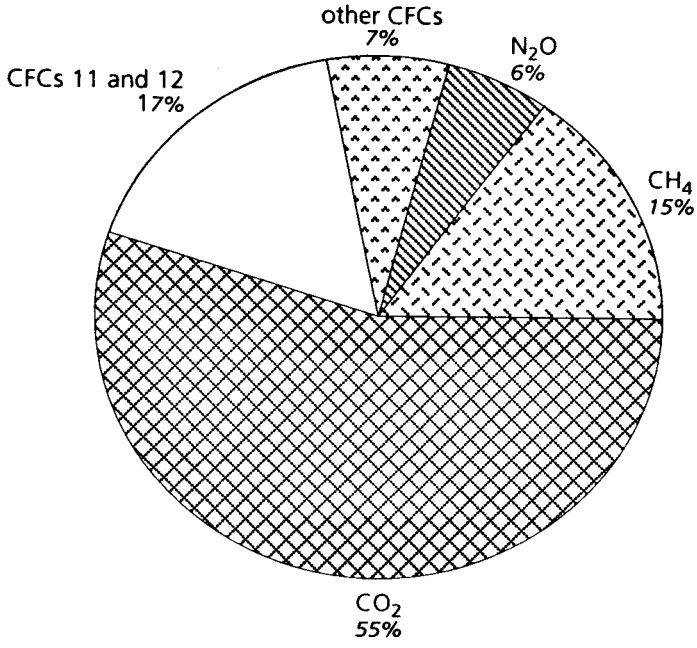

Figure 1: Contribution of greenhouse gases to global warming.

- Global mean surface air temperature has increased by 0.3 to 0.6°C over the last 100 years;
- Future warming rates will be about 0.2 to 0.5°C (average of 0.3°C) per decade;
- Doubling the CO_2 concentration will raise sea level two to four centimeters per decade (excluding melting of the polar ice caps).

SOURCES OF GREENHOUSE GASES

Although the composition of the atmosphere is known precisely, the composition and quantity of anthropogenic emissions are not known with great precision (see table 1). This knowledge is important to the establishment of policies to reduce emissions and eventually stabilize the composition of the atmosphere. Table 2 outlines an ambitious plan for stabilization. Some policies to reduce emissions might be more effective than others and might cost less.

Any plan for atmospheric stabilization must also address political consid-

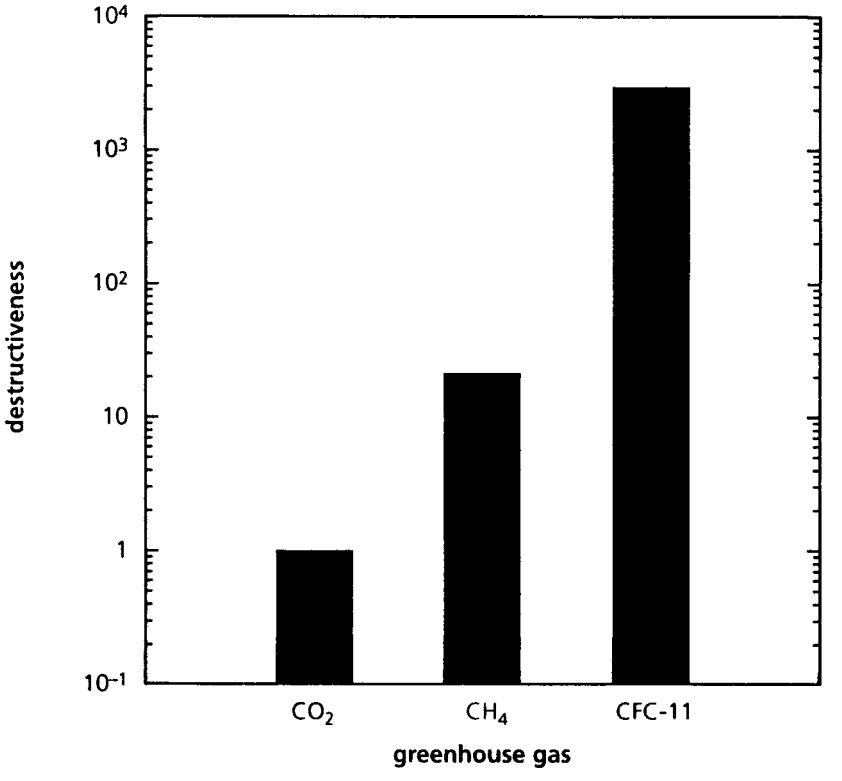

Figure 2: The relative destructiveness of a molecule of CFC-11 and CH_4 to a molecule of CO_2.

erations. For example, any effort to reduce oil consumption is unacceptable to OPEC countries. Another political consideration is the efforts made by developing countries to overestimate the contribution of deforestation, which in effect shifts the blame for global warming to developing countries.

A breakdown of the main sources and sinks of CH_4 and N_2O (given in tables 3 and 4) suggest which initiatives might be most promising to reduce emissions. Rice paddies are the most important anthropogenic source of methane, followed by enteric fermentation in ruminants. These emissions could be reduced by raising the types of ruminants and rice that emit the least methane. Landfills are also an important source of methane; methods of capturing this methane are currently being studied. There is substantial uncertainty in the values quoted in tables 3 and 4, and a great deal of research is needed to reduce this uncertainty.

One problem that deserves mention is a reduction of the uncertainties in deforestation (see table 5). As seen in table 1, deforestation contributes 1.6 ± 1.0 gigatons of carbon, which is 22 percent of total carbon emissions. There are

Table 2: Reductions in the anthropogenic emissions of greenhouse gases required to stabilize concentrations at 1990 levels.

Greenhouse gas	Reduction required
CO_2	>60%
CH_4	15–20%
N_2O	70–80%
CFC-11	70–75%
CFC-12	75–85%
HCFC-22	40–50%

no precise numbers on deforestation, and much controversy exists in the literature. A deforestation rate of 17 million hectares per year is frequently cited, but in all likelihood the actual rate is probably half that.[4] The policies of the Brazilian government have led to a remarkable decrease in deforestation in the Amazon.[5]

ACTING ON THE SOURCES: THE ROLE OF ENERGY CONSERVATION[6]

The primary cause of climate change is CO_2 emissions, which account for more than half the total effects. Energy production and deforestation are the main sources of CO_2. If present trends continue, CO_2 emissions will double in 30 to 40 years.

Figure 3 shows the growth of energy use in developing countries to be about three to four percent annually. In industrialized countries, energy use (and consequently CO_2 emissions) levelled off after 1975, while in developing countries the emissions have been steadily increasing and will continue to increase over the next 30 to 40 years due to population growth and economic progress.

As seen in figure 3, CO_2 emissions from developing countries will equal those of industrialized countries by the year 2010 or 2020 if no serious action is taken before then. As developing countries continue to increase their CO_2 emissions, emission-reduction efforts by developed countries will be less and less effective. Therefore, industrialized countries have a clear interest in help-

Table 3: Estimated sources and sinks of methane.

Sources	**Central value**	**Range**
	teragrams per year	
natural		
wetlands	115	100–200
termites	20	10–50
ocean	10	5–20
freshwater	5	1–25
methane hydrane	5	0–5
anthropogenic		
coal mining, natural gas and petroleum industry	100	70–120
rice paddies	60	20–150
enteric fermentation in ruminants	80	65–100
animal wastes	25	20–30
domestic sewage treatment	25	?
landfills	30	20–70
biomass burning	40	20–80
total	**515**	**331–850**
Sinks		
atmospheric (tropospheric, stratospheric) removal	470	420–520
removal by soils	30	15–37
atmospheric increase	32	28–37
total	**532**	**463–594**

Table 4: Estimated sources and sinks of nitrous oxide.

Sources	**Range** *Tg per year*
oceans	1.4–2.6
soils	
tropical forests	2.2–3.7
temperate forests	0.7–1.5
combustion	0.1–0.3
biomass burning	0.02–0.2
fertilizer	0.01–2.2
total	**4.4–10.5**
Sinks	
removal by soils	?
photolysis in the stratosphere	7–13
atmospheric increase	3–4.5
total	**10–17.5**

ing developing countries reduce their emissions.

Efficiency of energy use is usually measured by an indicator called *energy intensity*—the ratio of energy consumption (E) (measured usually in tons equivalent of petroleum per US$ 1,000) to gross domestic product (GDP). Long-term studies of energy intensity evolution in a number of countries indicate that this ratio increases in the initial phases of development when the heavy industrial infrastructure is put in place, then it peaks and decreases steadily (see figure 4). Only commercial energy consumption is considered in such figures. Long-term energy-intensity studies are difficult to analyze because technology, geography, population and history all play a role in determining energy intensity.

What the data indicate, however, is that most countries undergoing the development process follow the same pattern. The most recently developed show less accentuated peaks because they benefit from modern methods of manufacturing and efficient transportation systems. In other words, the *cou-*

Table 5: Deforestation estimates.[a]

annual global deforestation estimates *(million hectares)*					
	Myers 1980	**FAO/ UNEP[b] 1981**	**Myers 1989**	**FAO 1991**	**WRI 1990**
year of deforestation	1979	1976–1980	1989	1981–1990	late 1980s
closed canopy forest only	7.3	7.3	13.9	14.0	16.5
closed and open canopy forests	—	11.3	—	17.0	20.4

annual Brazilian deforestation estimates *(million hectares)*				
	INPE 1991	**Myers 1989**	**Fearnside et al. 1990**	**WRI 1990**
year of deforestation	1989	1989	1978–1989	late 1980s
total	**1.4**	**5.0**	**2.1**	**8.0**

a. Source: reference 3.
b. FAO/UNEP = Food and Agricultural Organization/United Nations Environment Program.

pling of energy and GDP growth, which was considered axiomatic, is not characteristic of modern economies. This peaking of energy intensity clearly started before the oil crisis of 1973, and the subsequent increase in oil prices only accelerated the pace of structural changes in the industrialized countries.

In contrast, as shown in figure 4, the energy intensity in the least developed countries (LDCs) is increasing. The adoption of outdated technologies provided to them by industrialized countries seems to be partially responsible. Another reason is the transfer of "dirty industries" and highly energy-intensive industries (such as aluminum smelters) to developing countries. However, this is not as serious as one might think because the world energy intensity (all countries taken together) is decreasing (see figure 5).

For developing countries to escape energy-related environmental and economic problems they must *leapfrog* the technological path followed by industrialized countries in the past. This means acquiring modern energy-efficient technologies as early as possible in the process of their development.

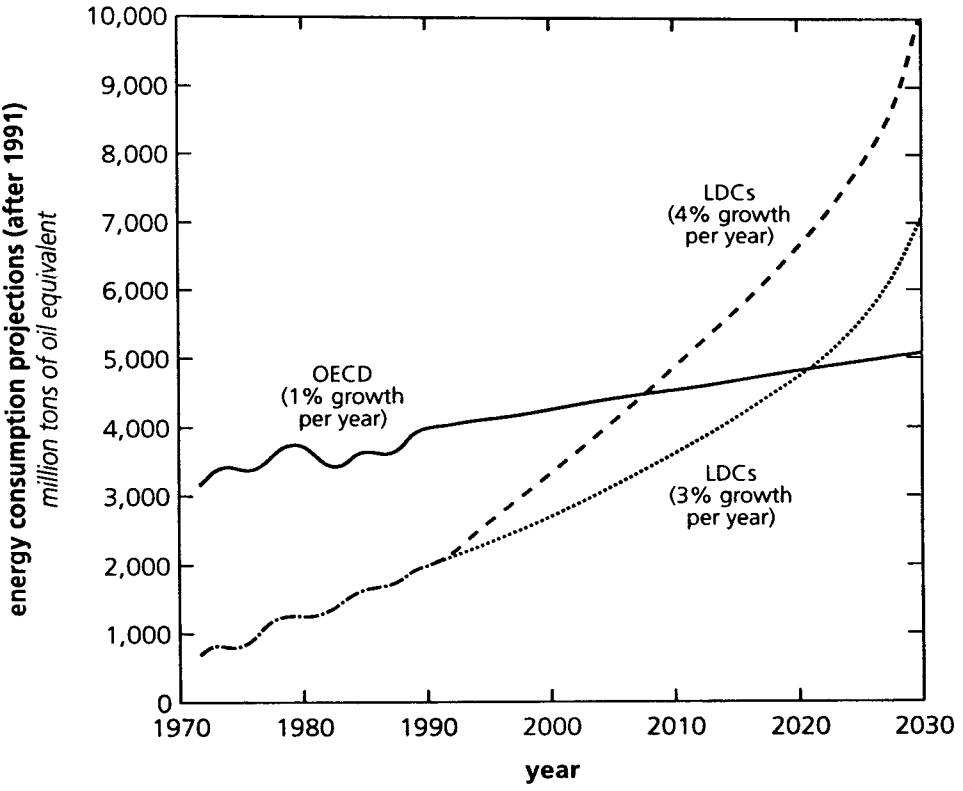

Figure 3: Evolution of the energy consumption in the countries of the Organization for Economic Co-operation and Development (OECD) and least developed countries (LCDs).

ACTING ON THE CO_2 SINKS: CO_2 SCRUBBING, AFFORESTATION AND ENHANCED BIOLOGICAL FIXATION

In addition to energy conservation and the reduction of deforestation, global warming can be slowed by recapturing CO_2 emissions, i.e., enhancing the sinks through one of the following methods:

- CO_2 scrubbing;
- Afforestation;
- Enhanced biological fixation.

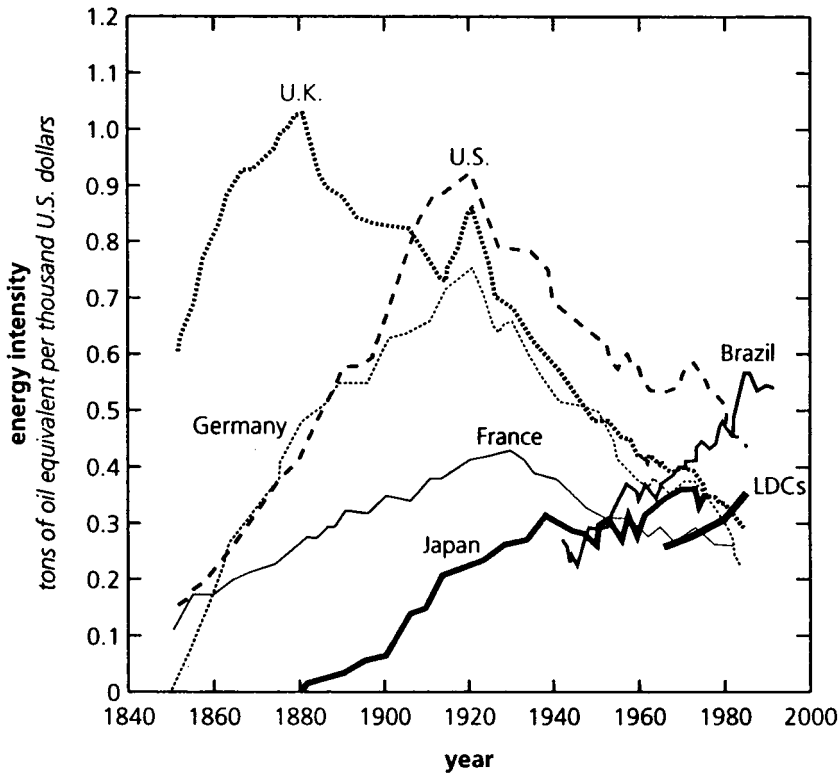

Figure 4: Evolution of energy intensity for a number of countries.

CO_2 Scrubbing[7]

In 1985, two gigatons of carbon was released into the atmosphere as the result of the burning of fossil fuels to generate electricity. Carbon dioxide in the flue gas of a power plant is about 500 times more concentrated than in the atmosphere. There are three methods of scrubbing CO_2 from flue gas: filtration, chemical absorption, and cryogenic distillation. They all have negative energy balances and cost from US$ 25 to 45 per ton of CO_2 removed.

The most promising method seems to be the use of membranes, but there is a tradeoff between permeability and purity of the CO_2 separated. The Japanese[8] are studying such membranes and conversion of CO_2 into methanol through CO_2 hydrogeneration (see figure 6).

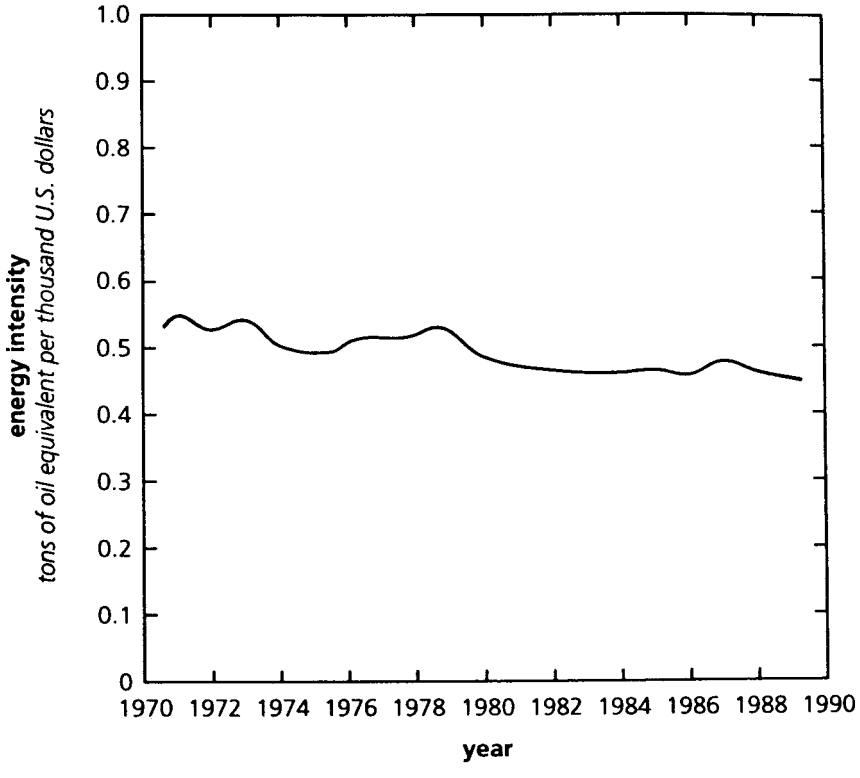

Figure 5: Evolution of world energy intensity.

Afforestation[8]

In tropical areas, growing trees can capture from five to 10 tons of carbon per hectare each year. One to two hundred million hectares of trees (one million square kilometers) could take up to one gigaton of carbon per year and offset the emissions due to fossil-fuel burning by 20 percent. Afforestation coupled with a reduction in deforestation could give us enough time to move beyond a fossil-fuel-based economy.

The cost for reforestation is around US$ 400 per hectare; to afforest 100 million hectares would cost US$ 40 billion. Covering enormous areas with artificial forests would produce much more wood than needed by any foreseeable commercial use. However, if this wood were used for energy production it would create a sustainable system of capturing carbon from the atmosphere. With the new technologies for gasifying wood and using it to generate electricity with gas turbines it might be possible to generate hundreds of gigawatts of electricity.

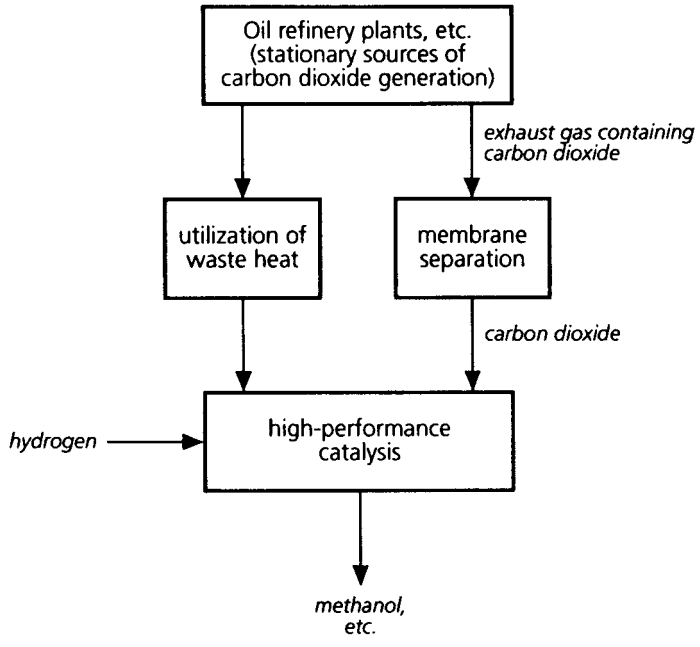

Figure 6: Schematics of a system for scrubbing CO_2 using membranes.

Enhanced Biological Fixation[9]

Photosynthesis by plants, algae and microorganisms seems to be a viable method of removing CO_2 from the atmosphere. Reforestation is taking place, but the impact has been small because of the low efficiency of natural photosynthesis. Thus, there are great efforts being made to develop higher-efficiency methods for CO_2 fixation. In Japan, research is focusing on:

- Discovering and breeding micro-organisms that are capable of highly efficient photosynthesis;
- Developing artificial breeding conditions for the most efficient photosynthesis, which could lead to high-density, large-volume industrial culture of micro-organisms.

Another way to dispose of CO_2 is to pump it into oil wells to enhance oil recovery. Storage of CO_2 in salt caverns has also been suggested, but the oceans seems to be the ultimate sink for CO_2 since there are already about 200 gigatons of CO_2 exchanged annually between the oceans and the atmosphere, and the total amount of carbon stored in the oceans is approximately 36,000 gigatons.

THE CLIMATE CONVENTION

Concern about climate change was serious enough to lead 154 countries (including the United States) to sign a Framework Convention on Climate Change at the United Nations Conference on Environment and Development (UNCED) that met in Rio de Janeiro, Brazil, in June 1992. The objective of the Convention (stated clearly in Article 2[10]) was to stabilize greenhouse gas concentrations in the atmosphere.

Article 3, item 3,[11] addresses three issues that took years to negotiate.

- The Convention adopted a "precautionary approach" to climate change, instead of the more active "adaptation strategy" proposed by some;
- The Convention accepted the idea that "lack of full scientific certainty should not be used as a reason for postponing action";
- The Convention focused primary responsibility on the industrialized countries.

However, it did not accept a ceiling on emissions at the 1990 level to be achieved by the year 2000. Although the freeze was not mandated, the Convention did include a statement that it was desirable to "return by the end of the present decade to earlier levels on anthropogenic emissions" (Article 4, items 2a and 2b[13]). R. Subroto, the Secretary General of OPEC, stated at the World Energy Council Meeting in Madrid in 1992[13] that he opposed "the imposition of measures based on questionable evidence and prejudicial intentions" but such opposition will probably not stop the implementation of the Convention.

The compromises reached in the Climate Convention were achieved through hard bargaining. The main participants had very different perspectives, namely:

- The United States adamantly opposed targets and timetables for CO_2 reductions because it would hurt some industries already affected by the Clean Air Act approved by the U.S. Congress in 1990;
- The "Group of 77" (developing countries) regarded the negotiations on climate change as another chance to obtain more aid and improve their trade relations. Environmental concerns gave the developing countries another weapon to be used in the North-South confrontation;
- The OPEC countries opposed any agreement that would lead to reductions in oil consumption or affect oil prices.

Ultimately, a few of the large developing countries (Brazil, China and India), with the active participation of some European countries, played a mediating role which led to the compromises cast in the Climate Convention, which can be summarized as follows:

- The developed countries agreed, in effect, to return to emissions at the 1990 level by approximately the year 2000;
- The Secretariat of the Convention will have considerable power to oversee the reduction of emissions.

POLICIES TO PREVENT CLIMATE CHANGE

The actions needed to prevent climate change, such as fostering end-use energy efficiency and the increased use of renewable energy, will not take place naturally on their own. In market economies there are two ways to encourage such actions: either a dramatic increase in the cost of fossil fuels or a significant decrease in the cost of clean energy. Even so it is unlikely that market forces alone would be successful in a timely way. Thus, non-market mechanisms must be introduced. Such mechanisms include regulations, and financial incentives and disincentives. Regulations (both national and international) could be imposed on utilities unless they reduce emissions voluntarily.

The Global Environment Facility (GEF) was created in 1991 as a three-year pilot project to provide grants for energy projects and technical assistance to reduce emissions. GEF was originally set up to assist developing countries deal with three main global environmental problems:

- Pollution of international waters, e.g., oil spills;
- Decreased biological diversity through degradation of natural habitats and mining of natural resources;
- Depletion of the stratospheric ozone layer caused by emissions of CFCs, halons and other gases.

The modest level of funding of GEF (approximately US$ one billion for three years) is an indication of the low level of importance attached to it by industrialized countries. All attempts to increase this level have failed, and the grandiose plans to double Official Development Aid (ODA) from its present level of US$ 50 billion per year (0.35 percent of the global GDP) to finance the activities contemplated in the AGENDA 21[14] adopted at the UNCED-92 have

Table 6: Financial pledges made at UNCED-92.

Country	GEF	ODA	Bilateral	AGENDA-21
Great Britain	3	—	—	—
Germany	0.5	0.5 over 3 yrs	—	—
U.S.	—	—	0.15	—
E.C.	—	—	—	4
Netherlands	—	2	—	—
Japan	—	7.7 over 5 yrs	—	—
France	—	4.3	—	—
total	**3.5**	**14.5**	**0.15**	**4**

not materialized.

In Rio, developed countries pledged approximately US$ 22 billion over five years for new activities related to environmental protection (see table 6). This is much lower than the US$ 125 billion per year proposed in AGENDA 21.

The restructuring of the GEF to conform to the guidelines embodied in the Climate Convention, as well as the replenishment of its funds, took place in early 1994; a two- to three-fold increase in GEF funding is expected. However, massive investments to prevent climate change are not yet in sight.

Global climate change could be averted if environmentally friendly energy technologies were given the same financial support as conventional sources of energy, namely large loans with low interest rates to be paid over long periods of time (20 to 30 years). With such support, advanced energy technologies could be economically competitive.

CARBON TAXES

The countries of the E.C. spend approximately one percent of their GDPs on environmental protection. In the United States, this number is two percent, and in most developing countries it is less than 0.5 percent. Worldwide, over US$ 200 billion dollars is spent for protection of the environment annually. Environmental projects include improving air and water quality, reducing the emission of industrial pollutants, protecting wildlife, and maintaining

national parks.

Twenty-five years ago there was almost no money spent for environmental protection. The Stockholm Conference of 1972 gave a great boost to the environmental movement, leading to the creation of government Ministries of the Environment and inspiring the "polluter pays" principle. After 1972, many countries accepted the additional burdens of environmental protection. Without any comprehensive international agreement, different nations, including developing ones, introduced environmental protection into their national agendas. No serious questions were raised about the resulting loss of jobs; on the contrary, the number of jobs probably increased. It is fair to say, however, that the environmental protection measures thus far considered have been of direct interest to the local population suffering the unpleasant consequences of air and water pollution.

We face now a greater challenge: the *global pollution* caused by the emissions of CFCs, CO_2 and other gases responsible for the "greenhouse effect." The climate changes resulting from these gases could be as serious or even more serious than the consequences of all types of local pollution taken together. Unfortunately, many countries are quite reluctant to pay for the measures needed to prevent climate change. Such measures include: energy conservation, a switch to less polluting fuels, the increased use of renewable sources of energy, and reforestation. More than 50 percent of the greenhouse effect is attributable directly to the way energy is produced and used today. There is nothing more reasonable than to apply the "polluter pays" principle to energy consumption and impose a *tax* on pollution produced, for example, a tax on the quantity of carbon produced. Two possible methods of taxation are:

- Impose a very heavy tax on carbon production of carbonaceous fuels in the hope that free market forces will lead to a reduction in consumption. This idea was proposed by White House economists two years ago and was immediately branded a scare tactic to frighten governments and politicians. Doubling or tripling the cost of fossil fuel was clearly politically unacceptable.

- Impose a small tax, such as 10 dollars per ton of carbon produced, which would be about one dollar per barrel of oil equivalent or a five percent tax. This tax would signal the importance of reducing global pollution and would also raise some US$ 50 billion worldwide (0.25 percent of the global GDP). Such money could be used to encourage a variety of actions that could prevent global change. In our view, *all* countries—including developing countries—should impose such a tax, although some of them could be exempted for limited periods of time. While exempted, they could modern-

ize their industries, which is not only in their interest but also in the interest of the developed countries.

It has been argued that the imposition of a tax (large of small) would have to be done by all nations simultaneously; otherwise some countries could benefit from lower production costs while others would lose energy-intensive industries. This is not necessarily so. Gasoline is very heavily taxed in some European countries and not in the United States but such differences have not produced great shifts in production patterns.

However, fiscal neutrality of carbon taxes also eliminates its educational value. Taxes should be considered equivalent to the purchase of insurance against global warming, and if the premiums are not paid now, there will be tremendous expenses in the future.

NOTES AND REFERENCES

1. S. Arrhenius, "On the Influence of Carbonic Acid in the Air upon the Temperature on the Ground," *Philosophical Magazine* **41** (1896) p. 237.

2. J.T. Houghton, G.J. Jenkins and J.J. Ephraus (editors), *Climate Change: The IPCC Scientific Assessment* (Cambridge: Cambridge University Press, 1990).

3. J.T. Houghton, B.A. Callender and S.K. Varney, *Climate Change: The Supplementary Report to the IPCC Scientific Assessment* (Cambridge: Cambridge University Press, 1992).

4. *World Resources 1993–1994*, World Resource Institute (Oxford: Oxford University Press, 1993).

5. D. Skole and C. Tucker, "Tropical Deforestation and Habitat Fragmentation in the Amazon: Satellite Data from 1978 to 1988," *Science* **260**, 1993, pp. 1905–1909.

6. A.K.N. Reddy and J. Goldemberg, "Energy for the Developing World," *Scientific American* **26** (3), 1990, p. 110–118.

7. N. Nakicenovic and A. John, "Carbon Dioxide Reduction and Reversal: Measures for the Next Century," *Energy* **16** (11/12), 1991, pp. 1347–1377.

8. RITE, 1992 Research Institute of Technology for the Earth, Kyoto, Japan.

9. T.B. Johansson, H. Kelly, A.K.N. Reddy and R.H. Williams (editors), *Renewable Energy: Sources for Fuels and Electricity* (Washington DC: Island Press, 1993).

10. Article 2 of the Climate Convention, "The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

11. Article 3, item 3, of the Climate Convention, "The Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mit-

igate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost effective so as to ensure global benefits at the lowest possible cost. To achieve this, such policies and measures should take into account different socio-economic contexts, be comprehensive, cover all relevant sources, sinks and reservoirs of greenhouse and adaptation and comprise all economic sectors. Efforts to address climate change may be carried out cooperatively by interested Parties."

12. Article 4, item 2a and item 2b of the Climate Convention, "Each of these Parties shall adopt national policies and take corresponding measures on the mitigation of climate change, by limiting its anthropogenic emissions of greenhouse gases and protecting and enhancing its greenhouse gas sinks and reservoirs. These policies and measures will demonstrate that developed countries are taking the lead in modifying longer-term trends in a anthropogenic emissions consistent with the objective of this Convention, recognizing that the return by the end of the present decade to earlier levels of anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol would contribute to such modification."

Article 4, item 2b, "In order to promote progress to this end, each of these Parties shall communicate, within six months of the entry into force of the Convention for it and periodically thereafter, and in accordance with Article 12, detailed information on its policies and measures referred to in subparagraph (a) above, as well as on its resulting projected anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol for the period referred to in subparagraph (a), with the aim of returning individually or jointly to their 1990 levels these anthropogenic emissions of carbon dioxide and other greenhouse gases not controlled by the Montreal Protocol."

13. R. Subroto, "Energy and Cooperation," World Energy Council, 15th Congress, Madrid, 20–25 September 1992.

14. AGENDA 21 was a non-binding document accepted by all countries attending the UNCED in Rio de Janeiro in June 1992. It outlines a set of protocols to achieve "sustainable development" and estimates the costs incurred.