Note: Figure 1a, 1b, & Figure 1 in the main text are not available and Figures 1, 2 in Appendix to be improved

ANALYTICAL FRAMEWORK FOR THE REDUCTION OF GREENHOUSE GAS EMISSIONS [1]

1. Introduction

Human activities are now thought to have the potential to alter significantly the Earth's climate on a global scale. This potential derives from increasing atmospheric concentrations of the greenhouse gases which are predicted to warm the earth's lower atmosphere and surface by reducing the efficiency with which it cools to space. The amount of warming depends on the magnitude 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. The most important greenhouse gases are water vapor, carbon dioxide, methane, nitrous oxide, halocarbons (e.g., the chlorofluorocarbons), and upper-tropospheric and lower- stratospheric ozone.

The atmospheric concentrations of carbon dioxide, methane, nitrous oxide, halocarbons and tropospheric ozone are primarily increasing because of energy and agricultural practices. It should be noted, however, that during the last few years there has been an increasing recognition that some of the predicted global warming may have been offset, especially in the northern hemisphere, because industrial activities and biomass burning have increased the concentrations of atmospheric aerosols that reflect incoming solar radiation thus tending to cool the earth's lower atmosphere and surface. In addition, the observed decrease in the concentration of ozone in the lower stratosphere at all latitudes, except the tropics, over the last two decades may have offset the greenhouse affect of the halocarbons.

2. Sources of Greenhouse Gases

Carbon dioxide: The two primary sources of the observed increase in atmospheric carbon dioxide are combustion of fossil fuels and land-use changes; cement production is a further minor, but not insignificant, source. The best estimate for global fossil fuel emissions in 1990 is 6.0 ± 0.5 GtC
(1 GtC (gigatonne of carbon) equals one billion [one thousand million (10^9)] tonnes of carbon). The direct net flux of carbon dioxide from land-use changes (primarily deforestation), integrated over time, depends upon the area of land deforested, the rate of reforestation and afforestation,

[1] This analytical framework has been produced by modifying the Report of the Ad-Hoc Working Group On Global Warming and Energy (AWGGWE) which met at the Center for Energy and Environmental Studies, Princeton University, Princeton (NJ), USA, on June 14-15, 1991, to discuss the paper prepared by Amulya Reddy for the AWGGWE on the basis of discussions of his preliminary note at the Scientific and Technical Advisory Panel (STAP) meeting held in Geneva April 22-24, 1991, and other inputs. The modifications have taken into account comments received on the AWGGWE Report.

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. The best estimate of annual average net flux to the atmosphere from land-use change during the decade of the 1980s is of 1.6 ± 1.0 GtC. 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.

Methane: A total (anthropogenic plus natural) annual emission of methane of about 500 Tg (1 Tg equals 10^{12} grammes equals one million tonnes) 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 500 Tg methane, there are still many uncertainties in accurately quantifying the magnitude of emissions from individual sources (natural wetlands, rice paddies, enteric fermentation from cattle, landfills, coal mining, oil, natural gas). Human activities are thought to currently account for about 60-70% of the total emissions. Recent methane isotopic studies suggest that approximately 100 Tg methane (20% of the total methane source) is of fossil origin, largely from the coal, oil, and natural gas industries. Recent studies of methane 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, and may be much smaller than previously estimated.

Nitrous Oxide: The sum of all known anthropogenic and natural sources of nitrous oxide is barely sufficient to balance the calculated atmospheric sink (stratospheric photolysis) or to explain the observed increase in the atmospheric abundance of nitrous oxide. Recently, 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.

Halocarbons: The worldwide consumption of chlorofluorocarbons 11, 12, and 113 is now 40% below 1986 levels, substantially below the amounts permitted under the Montreal Protocol. Further scheduled emissions reductions are mandated by the 1990 London Amendments to the Montreal Protocol leading to a complete phase-out of all long-lived chlorofluorocarbons by the year 2000. As chlorofluorocarbons are phased out, hydrochlorofluorocarbons and hydrofluorocarbons will substitute, but at lower emission rates.

Ozone: About 90% of atmospheric ozone resides in the stratosphere and about 10% in the troposphere. Ozone is an effective greenhouse gas in the upper troposphere and lower stratosphere (i.e., 8-25 km altitude). Significant decreases have been observed in the total column content of ozone during the last two decades at all latitudes, except the tropics, throughout the year with the downward trends being larger during the 1980s than in the 1970s.

Stratospheric Ozone: The decreases in stratospheric ozone have occurred predominantly in the lower stratosphere (below 25km), where the rate of decrease has been up to 10% per decade depending on altitude. The weight of scientific evidence suggests that anthropogenic chlorine - and bromine-containing halocarbons are responsible for the observed reductions in middle- and high latitude stratospheric ozone. 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. Consequently, ozone depletion at these latitudes is predicted to continue unabated through the l990s.

Tropospheric Ozone: There is evidence to indicate that ozone levels in the troposphere up to 10 km altitude above the few existing ozonesonde stations at northern middle latitudes have increased by about 10% per decade over the past two decades. The abundance of carbon monoxide, an ozone precursor in the troposphere, appears to be increasing in the northern hemisphere at about 1% per year, however, there is little information on the global trends of other tropospheric ozone precursors (non-methane hydrocarbons and oxides of nitrogen). Each of these ozone precursors have significant natural and anthropogenic sources, but their detailed budgets remain uncertain.

3. Relationship Between Emissions and Atmospheric Concentrations

A key issue is to relate emissions of greenhouse gases and greenhouse gas precursors to future concentrations of greenhouse gases in order to assess their impact on the radiative balance and thereby the Earth's climate. A number of different types of carbon cycle and tropospheric chemistry models have been developed for this purpose. However, it should be noted that all carbon cycle models are subject to considerable uncertainty because of an inadequate understanding of the processes controlling the uptake and release of carbon dioxide from the oceans and terrestrial ecosystems. Similarly, tropospheric chemistry models exhibit substantial differences in their predictions of changes in ozone, and in other chemically important active gases due to emissions of methane, non-methane hydrocarbons, carbon monoxide and, in particular, oxides of nitrogen, because of uncertainties in the knowledge of background chemical composition and our inability to represent small-scale processes occurring within the atmosphere.

4. Global Warming Potentials

Gases can exert a radiative forcing both directly and indirectly -- direct forcing occurs when the gas itself is a greenhouse gas; indirect forcing occurs when chemical transformation of the original gas produces a gas or gases which themselves are greenhouse gases. The concept of the Global Warming Potential (GWP) has been developed for policy-makers as a measure of the possible warming effect on the surface-troposphere system arising from the emission of each gas relative to carbon dioxide. The indices are calculated for the contemporary atmosphere and do not take into account possible changes in chemical composition of the atmosphere. Changes in radiative forcing due to carbon dioxide, on a mass (e.g., kg) basis, are non-linear with changes in the atmospheric carbon dioxide concentrations. Hence, as carbon dioxide levels increase from present values, the GWPs of the non-carbon dioxide gases would be higher than those evaluated here. For the concept to be most useful, both the direct and indirect components of the GWP need to be quantified.

Direct Global Warming Potentials: The direct components of the Global Warming Potentials (GWPs) have been calculated, taking into account revised estimated lifetimes, for a set of time horizons ranging from 20 to 500 years, with carbon dioxide, as the reference gas. The table below shows values for a selected set of key gases for the 100-year time horizon. The carbon cycle model used in these calculations probably somewhat underestimates both the direct and indirect GWP values for all non-carbon dioxide gases. The magnitude of the bias depends on the atmospheric lifetime of the gas, and the GWP time horizon.

Indirect Global Warming Potentials: Because of our incomplete understanding of chemical processes, most of the indirect GWPs reported in IPCC (1990) are likely to be in substantial error, and none of them can be recommended. However, it is clear that the indirect GWP for methane is positive and could be comparable in magnitude to its direct value. In contrast, the indirect GWPs for chlorine and bromine halocarbons are likely to be negative because they are likely to be the cause of the observed global ozone depletion in the lower stratosphere. The concept of a GWP for short-lived, inhomogeneously distributed constituents, such as carbon monoxide, non-methane hydrocarbons, and oxides of nitrogen may prove inapplicable, although, as noted above, we know that these constituents will affect the radiative balance of the atmosphere through changes in tropospheric ozone and the hydroxyl radical, which controls the atmospheric lifetime of many tropospheric species such as methane and hydrochlrofluorocarbons. Similarly, a GWP for sulfur dioxide is viewed to be inapplicable because of the non-uniform distribution of sulphate aerosols.

Global Warming Potentials (100 year time horizon)

GAS	DIRECT GWP	SIGN OF INDIRECT GWP
Carbon dioxide	1	none
Methane	11	positive
Nitrous oxide	270	uncertain
CFC-11	3400	negative
CFC-12	7100	negative
HCFC-22	1600	negative
HFC-134a	1200	none
Carbon monoxide	--	positive
Oxides of nitrogen	--	uncertain
Non-methane hydrocarbons	--	positive

* The GWP values are dependent upon the time horizon chosen because of the different atmospheric lifetimes of the gases, e.g., the direct GWPs for methane for 20 and 500 year time horizons are 35 and 4, respectively.

5. Relative Importance of Greenhouse Gases

Combining the 1990 emissions of greenhouse gases with their global warming potentials suggests that the most important greenhouse gas directly influenced by human activities is carbon dioxide, with methane being the second most important. More than half of the enhanced greenhouse affect can be attributed to carbon dioxide, with methane being responsible for up to another quarter.

6. Future Emissions of Greenhouse Gases

Future emissions of greenhouse gases will depend upon a wide range of economic, demographic and policy conditions and are inherently controversial to predict because they reflect different views of the future. Considerable uncertainties surround the evolution of the types and levels of human activities (including economic growth and structure), technological advances, and human responses to possible environmental, economic and institutional constraints. Consequently, predicting future emissions of greenhouse gases from fossil fuel and biotic sources is inherently difficult because it requires embodying a wide array of assumptions on factors such as population growth, economic growth, structural changes in economies, role of nuclear power, fossil fuel availability, energy prices, technological advances, the rate of diffusion of renewable energy technologies, changes in land-use patterns (particularly rates of deforestation), food demand, agricultural productivity, and land tenure policies.

It is, clear, however, that if present trends persist, it is very likely that the resulting impacts on the global atmosphere will lead eventually to changes of the global climate that seriously perturb human societies and perhaps even endanger human life. Further, the response time of the climate system is such that by the time significant changes are detected it may be too late to rectify the situation. This is why even though there is still much scientific disagreement on the extent and likely consequences of global warming, many countries are committed to putting precautionary policies in place, of which the GEF is a part. The idea is that, as further evidence on global warming and its consequences is gathered, the investments of the GEF will leave the international community better-placed to reduce carbon accumulations to safe levels, over the long term, should the need arise. The approach can be described either as an insurance policy or as "preventive maintenance" in engineering parlance, i.e., taking steps to avoid breakdowns that necessitate repair. Among these steps are those directed towards the reduction of greenhouse gas emissions. However, virtually all these steps involve investments and therefore there has to be strategy for reducing greenhouse gas emissions.

7. Least-Cost Emissions Planning -- the Ideal Approach

Investments should be directed towards that **mix** of technologies[2]

[2] The word "technologies" has been used here to be synonymous with "projects" in the sense that every project presumes a technology upon which it is based and every technology can be used to design a project around it.

which can achieve the maximum reduction in emissions for a given investment. The identification of such a mix requires information on the unit cost of emissions reduction for the various techno logies and the magnitude of the emissions reduction achievable with these technologies.

If this information were available, one could adopt a least -cost emissions-reduction strategy based on cost -emissions-reduction-technology (CERT) curves. These curve s are constructed (cf. Appendix 1) by choosing the technology with the lowest unit cost of emissions reduction as the first element of the mix, exploiting its emissions reduction potential, choosing the next most expensive technology as the second element of the mix, and so on. Thus, one can either estimate the total investment that is required for the mix of technologies to achieve a given magnitude of emissions reduction or one can identify which mix of technologies is likely to achieve the maximum emiss ions reduction for a given total investment.

Least-cost-emissions planning is a worthwhile approach to move towards, for several important reasons:

- it takes into account both the cost -effectiveness of a technology in reducing greenhouse gas (GHG) emis sions as well the potential impact of that technology with regard to emissions -reduction;
- it treats the supply-side and demand-side options for reducing GHG emissions on equal terms and does not discriminate against either of them;
- it ensures that different technologies are compared and prioritized on the basis of their cost-effectiveness (unit costs and potential emissions-reduction);
- it provides some idea of how much reduction in emissions is achievable (say, in percentage terms) and what cost;
- it constitutes a powerful heuristic for developing an investment strategy and portfolio for reducing GHG emissions.

Unfortunately all this is easier said than done because of the many conceptual and methodological problems in computing the costs of interventions and in estimating the benefits or effectiveness. In the first place, there has to be an agreed methodology of computing the costs of an emissions-reduction technology, and in particular the incremental costs over and above the conventional tec hnology. And, thee benfits depend upon the objective of the intervention. If what was needed was, say, for the OECD and CIS countries to reduce gradually their net CO_2 emissions from energy production and use by 20%, relative to today's levels, and for developing countries to reduce the rate of growth of energy consumption from 6% per year to 4% per year (a major reduction), then this could be accomplished by reforming energy pricing policies andd other measures to improve energy efficiency. However, eve n with such improvements in energy efficiency, global CO_2 emissions each year wouls still be twicee their present levels in 40 years time and carbon accumulations would likewise be twice theirr present levels by the middle of the century; the global warming problem would have been delayed a decade or two, but would have been substantially unaddressed. It is more important to have the objective of stabilizing carbon accumulations in the atmosphere at somee safe level over the long term. Thus, effectiveness cannot be divorced from objectives and benefits cannot be separated from targets.

8. Costs of Stabilizing/Reducing Carbon Accumulations

Consider a situation (Figure 1a) in which carbon accumulations are rising over time due to the dependence on conven tional fossil-fuel energy technologies. If a limit is set on the safe level of accumulations, then it would be necessary to switch eventually to the non -fossil alternatives. Suppose, for heuristic purposes, the switch is assumed to take place at the timee T in a step-function fashion (Figure 1b), then the marginal cost of energy consumption would change from the fossil -fuel value of "f" to the marginal costss of the non-fossil fuel alternatives, "n". Then, the present value of the extra marginal cost at the time t = 0 is

$$c_0 = (n-f)(1+r)^{-T}$$

Thus, the actual marginal cost of fossil fuel consumption is f_0+c_0 and c_0 is the carbon tax

9. Technologies for Least-Cost Emissions Planning

What characteristics should technologies possess before they are considered for inclusion in least-cost emissions planning? In particular, what should be the state of readiness of the technologies?

It is well-known that before a technology penetrates the economy, it has to pass through several stages:

- the technology must be "right" -- its technical potential should have been achieved through research and development, and awareness of this potential should be widespread among technology -adopters through demonstration, communication and experience, i.e., the R & D must be complete and the technology must be proved and demonstrated;
- the costs must be "right" -- its economic potential should have been realized through cost-reduction based on mass production and organizational learning (in the case of modest -scale and modular technologies);
- the market must be "right" -- its market potential should have been realized by ensuring that market imperfections are overcome and market barriers are surmounted.

A fundamental distinction can, therefore, be drawn between two classes of technologies:

- already-available technologies that have penetrated (or are ready to penetrate) the economy because they are technologically proven and economically viable and the market environment for them is conducive
- potentially-available technologies that promise even greater global environmental benefits than the already -available technologies if they can become implementable by making the technology, economics and market "right" even though at present they are not yet "right".

The potentially-available technologies yield, for the same total investment, a greater emissions reduction than that for the already - available technologies that have penetrated the economy. In other words, the potentially-available set includes technologies corres ponding to a lower investment for the same emissions reduction, and therefore, the adoption of this class of technologies may reduce emissions reduction costs significantly.

But, <u>mainstream financing mechanisms are unlikely to support the potentially-available class of technologies</u> -- these technologies tend to be viewed as unviable because they have not shown the ability to penetrate the market. Hence, they require special funding mechanisms to make them technologically proven, economically viable and to demonstrate how to make the market environment conducive for them. In such a situation, the special funding mechanisms must assist the technology in the potentially-available class to achieve its full emissions-reduction potential by

- making the technology "right" through demonstration of the technology (assuming that the R & D is over);
- making the costs "right" through improvements in the cost-effectiveness of the technology, for instance, through mass production and through organizational learning in the case of modest-scale and modular technologies;
- making the market environment "right" through pilot experiments that demonstrate how to overcome the barriers to the smooth and effective functioning of the market.

In addition to the "readiness" of a technology to penetrate the market, there is also the question of the emissions reduction potential of the technology.

Taking both these factors into account, several categories of technologies can therefore be identified:

- the growth-oriented set (GOS) of technologically proven, economically viable and market-worthy technologies to promote the economic growth of a country
- the globally environmentally sound set (GESS) of technologies that advance the protection and improvement of the global environment
- the set (PAGESS) of potentially-available globally environmentally sound technologies that promise even greater global environmental benefits than the already-available technologies, but are handicapped by the fact that they are not yet ready for implementation when they can be made implementable with a special funding mechanism.

These three sets of technologies can be represented by three circles with various degrees of overlap (Figure 1 on next page). Several conclusions can be drawn from such a diagram.

<u>Conclusion #1:</u> Unless a technology is technologically proven and economically viable, it will not appear in the country's portfolio -- hence, there will be zero overlap between the not-yet-ready set (PAGESS) of potentially-available technologies and the growth-oriented set (GOS).

<u>Conclusion #2:</u> If the globally environmentally sound set (GESS) of technologies overlaps completely with the growth-oriented set (GOS) of technologies, then the mainstream financing that supports the latter will by itself provide emissions reduction as a bonus -- no special environmental funding is necessary[3].

<u>Conclusion #3:</u> If there is only partial overlap between the globally environmentally sound set (GESS) of technologies and the growth-oriented

[3] In other words, all projects with <u>social</u> rates of return greater than the cut-off rate produce desirable emissions reductions.

set (GOS), then sole dependence on mainstream financing will exclude technologies in the GESS set, because they cannot be justified on the basis of the country's economic criteria however important they may be from a global emissions-reduction point of view -- in this case, special environmental funding is essential to harness the emissions-reduction potential of the excluded technologies.

Conclusion #4: In order to achieve the maximum emissions reduction, it is not sufficient to rest content with the globally environmentally sound set (GESS) of technologies that qualify for mainstream financing. It is necessary to enlarge the choice by including for implementation not-yet-ready but environmentally promising technologies from the PAGESS set of potentially-available technologies. But this means that not-yet-ready technologies must be assisted to achieve their full technical, economic and market potential before they can spread with mainstream financing. This assistance can only be provided by special funding mechanisms.

10. Technologies for GEF Funding

Hence, a special funding mechanism such as the Global Environment Facility (GEF) has a unique and key role in protecting the global environment -- a role that cannot be achieved through mainstream financing. This role consists of supporting projects involving two categories of technologies:

(1) technologies that promise even greater benefits than the already-available technologies but are handicapped by the fact that they are not yet ready for implementation (these may be called Type I)

(2) technologies that would be excluded from a country's portfolio on economic grounds even though they confer global environmental benefits (these may be called Type II).

There is a fundamental difference between these two categories of technologies. Though the Type II category has already achieved its full technical, economic and market potential and can therefore be supported by conventional financing mechanisms, it would be excluded from a country's portfolio because it is costlier than "dirtier" technologies which tend to be chosen in capital-scarce situations. In contrast, the Type I category has not yet achieved its full potential (it may require demonstration, cost reduction, pilot-phase dissemination trials, etc.) and therefore cannot do without a special funding mechanism such as the GEF.

There is another way of looking at the distinction. Normally, technologies that qualify for mainstream World Bank financing disqualify themselves for GEF funding. However, if there are technologies that cannot be justified on the basis of the country's criteria and would therefore be excluded even though global environmental benefits would flow from them, special environmental GEF funding is essential to harness the emissions-reduction potential of the excluded technologies. In other words, if the criteria of mainstream financing such as the World Bank are identical to the country's criteria[4], then one can say that GEF supports globally desirable projects whereas mainstream financing only supports nationally desirable projects.

With regard to Type I technologies, after a special funding mechanism

[4] And this need not be the case!

such as GEF assists this type to achieve its full technical, economic and market potential, mainstream financing can take over -- hence, there is a "upward compatibility" of the GEF funding of this category of technologies with World Bank funding. GEF must only run the first leg of the "Race to Save the Planet"; when it has helped to get the technologies, costs and markets "right", and worked out how the project can be replicated elsewhere, GEF must hand over the baton to the World Bank.

The special funding mechanism, GEF, must focus on making technologies implementable, rather than on disseminating technologies which is a task for mainstream WB financing. Thus, GEF should support the development of implementation packages identifying and specifying all the hardware as well as the software (policies, policy instruments, policy agents, institutions, financing, management, etc.) required to utilize the hardware and make it spread in the economy.

11. Criteria for GEF funding

The analytical framework that has been developed above leads the following set of criteria for GEF funding for reducing and limiting greenhouse gas emissions. In the first place, the project should satisfy the following necessary criteria:

1. A successful project should lead to potential benefits for the global environment in terms of reducing the net emissions of greenhouse gases.

2. The setting in which the project will be implemented should be ready enough to ensure that the project has a good chance of succeeding in its objectives.

3. The project should be capable of being developed and approved in a time period short enough to match the GEF time horizon.

If there are definite constraints on the funds available -- as is the case with the present pilot phase of GEF -- it would be advantageous if the restricted funds are used to innovate. Thus,

4. Other things being equal, a GEF pilot-phase project should be innovative and do something new.

Obviously, as GEF or some GEF-like mechanism moves into its operational phase, the premium on innovativeness will diminish and the projects need not necessarily be novel. Rather, their cost-effectiveness and beneficial impact on the global environment are far more important.

But, the above criteria are not sufficient; in addition, the project should satisfy one or more of the following criteria.

5. Without GEF funding, the project should face exclusion from the country's portfolio even though it has significant global environmental benefits.

6. Though a project may satisfy the criteria (1) to (4), it may involve an emissions-reduction technology (ERT) that has not yet achieved its full technical, economic and market potential even though its emissions-reduction potential may be far greater than that of the technologies conventionally deployed. The realization

of the emissions-reduction potential of such a promising technology requires that it must be assisted to achieve its full technical, economic and market potential because mainstream financing will not deem it ready for support.

In the case of a project involving such a promising ERT that has not yet achieved its full technical, economic and market potential, at least one of the following sub-criteria must be met to make the project eligible for GEF selection:

6.1 Given that an emissions-reduction technology (ERT) is technically feasible (in the sense that the research and development are complete) but not yet proven, GEF support is necessary to demonstrate the technology and prove its functioning;

6.2 Given that an ERT has been technically proven, GEF support is necessary to make it economically viable by getting the costs "right", i.e., the technology needs to capture the economies of mass production and organizational learning (in the case of modest-scale and modular technologies);

6.3 Given that an ERT is economically viable (using accepted social rather than consumer/financial criteria), GEF support is necessary to demonstrate how to make the ERT marketable by showing how to overcome the market imperfections and surmount the market barriers;

6.4. GEF support makes the ERT implementable because it would not be implemented without this demonstration and proof of implementability.

7. To ensure the replicability of the project both within the country and in other countries, the project should:

7.1 result in the preparation of complete implementation packages identifying and specifying all the hardware as well as the software (policies, policy instruments, policy agents, institutions, financing, management, etc.) required to utilize the hardware and make it spread in the economy.

7.2 ensure that performance evaluation plans, such as monitoring of actual greenhouse gas reduction measures and their cost-effectiveness, should be built into the project.

Of course, it will be a bonus if a project

8. has the potential of yielding eventual multiple benefits, i.e., benefits to other GEF areas.

The above criteria must be seen as necessary conditions to be satisfied for GEF eligibility, i.e., if the project does not satisfy these criteria, it disqualifies itself and becomes ineligible for inclusion in the set of projects identified for GEF consideration. But, the criteria are not sufficient to make a project qualify for funding; for that, it is necessary that the project area should be considered as a priority area (cf. Appendix 2 on Priorities) and that the project should have intrinsic merit.

12. Types of Interventions to reduce and limit Emissions of Greenhouse Gases

The main types of interventions to reduce and limit emissions of greenhouse gases are as follows:

- Improvements in End-use Efficiency
- Reduction of Emissions Intensity of Energy Production
- Encouragement of shifts to beneficial energy carriers and transport modes
- Reductions of emissions of non-carbon dioxide GHGs
- Transmission and Distribution Efficiency
- Emissions Reduction at the point of End-use
- Combatting deforestation
- GHG sequestration

13. Priorities for GEF Funding

The above categories of interventions that can result in a reduction of GHG emissions and in sequestration of GHG can be used to develop a list of project areas (cf. Section 4 of Appendix 2) that merit consideration for GEF funding. Because the list of projects in Section 4 of Appendix 2 is very large, it is unlikely to be of much use in practice. Hence, it is essential to prioritize the projects.

Ideally, the prioritization should be done on the basis of least-cost emissions-reduction planning so that a selection can be made of all the technogies/projects that constitute the mix of technologies that yield the maximum potential emissions reduction for a given investment. Within this mix, the technologies can be ranked according to increasing unit cost of emissions reduction, i.e., decreasing cost-effectiveness. Alternatively, they can be ranked according to decreasing magnitude of (potential) emissions reduction.

To operate this prioritization procedure, it is necessary to have reliable data on the unit cost of emissions reduction and the magnitude of potential emissions reduction of the various technologies. Unfortunately, this data is not readily available in a standardized and assembled form. An urgent task, therefore, is to assemble this data.

One can also initiate a process of giving to each project a score by using each criterion, assigning marks say on a one-to-ten scale, multiplying these marks by an agreed weighting factor and then adding the weighted marks for all the criteria. Such a process should be initiated as soon as possible. The projects can then be prioritized on the basis of their scores.

In the meantime, the only prioritization that can be done immediately is that based on synthesizing the priorities assigned by experts along with the rationale for these priorities.

Taking into account the criteria, the experts of the Ad-hoc Working Group on Global Warming and Energy assembled by STAP have suggested allocations between different generic types of intervention that would lead to a reduction of emissions of greenhouse gases interventions areas. A consensus was reached in favour of the following allocations between these types of interventions related to emissions reduction:

- o Improvements in End-use Efficiency 35%
- o Reduction of Emissions Intensity of Energy Production ...30%
- o Encouragement of beneficial shifts in energy carriers transport modes 10%
- o Reductions of emissions of other GHG s 15%

and the balance of 10% for other areas, viz.,

- Transmission and Distribution Efficiency
- Emissions Reduction at the point of End-use
- Combatting deforestation
- GHG sequestration

Within the above generic types of intervention for which 90% of GEF funding has been suggested, the following 14 project areas have been recommended by the experts as being of high priority.

A. Improvement of end-use efficiency

- o Reduction of energy intensity of basic materials
- o Efficient motors and drives
- o Lighting
- o Irrigation Pumpsets
- o Vehicle Fuel Efficiency
- o Water Heating

B. Reduction of Emissions Intensity of Energy Production

- o Photovoltaics
- o Biomass Gasifiers/Gas Turbines
- o Growing and using biomass sustainably to replace fossil fuels
- o Advanced efficient gas turbine cycles

C. Encouragement of Beneficial Fuel and Transport Modal Shifts

- o Transport Modal Shifts

D. Reduction of non-CO_2 Greenhouse Gases

- o Urban and Rural Waste Treatment
- o Reduction of flaring/venting of natural gas
- o Reduction of releases associated with coal mining

It is suggested that 80% of the allocation for each generic area A, B, C and D be directed to the priority project areas within the generic area and the balance for other promising project areas not listed here.

13.1. <u>Research Activities</u>

A small percentage of funds, say 5%, should be used for research activities <u>targeted to support GEF objectives in general and GEF projects in particular</u>.

Two categories of research activities must be assigned priority:

1. In parallel with each GEF project, research must be carried out to permit least-cost emissions-reductions planning based on

combining the unit cost of emissions reductions and the potential emissions reductions for various options into cost-emissions-reduction-technology (CERT) curves.

2. A research component should be built into every project for measuring the actual performance and cost-effectiveness of the greenhouse gas emissions reduction measure.

APPENDIX 1: COST-EMISSIONS-REDUCTION-TECHNOLOGY CURVES

1. Emissions of Greenhouse Gases

The magnitude (EGHG) of the emissions of greenhouse gases (GHG) may be described very simply with the formula:

$$EGHG = GDP \times \frac{EGHG}{GDP} = GDP \times EIE \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where EIE = Emissions Intensity of the Economy.

A total investment I (on capital and on operation and maintenance (O & M) costs) can produce changes in the emissions of greenhouse gases, ΔEGHG, via changes in the emissions intensity of the economy, ΔEIE, and changes in the GDP, ΔGDP:

$$\frac{\Delta EGHG}{I} = \left\{GDP \times \frac{\Delta EIE}{I}\right\} + \left\{\frac{\Delta GDP}{I} \times EIE\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

If a condition is imposed that investments should not produce decreases in the GDP, and in fact, they should produce increases in GDP, then it is necessary that investments should produce decreases in the emissions intensity of the economy in order to produce an overall reduction in the emissions of greenhouse gases. Thus, reductions of the emissions of greenhouse gases should be achieved by reducing the emissions intensity of the economy. Generic ways of achieving this reduction in the emissions intensity of the economy are discussed in the companion note (Appendix 2) on Priorities for GEF Funding to combat Global Warming.

The expression (2) for the impact of investments on the reduction in the emissions of greenhouse gases has two interesting implications.

(i) It is possible that an investment I can produce a positive ΔGDP along with a negative ΔEIE, i.e., an increase in the GDP along with a reduction in the emissions of greenhouse gases. Clearly, such investments that benefit both the environment and development are preferable to investments that solely benefit the environment to the same extent. In fact, in developing countries, investments that resolve the so-called environment-development conflict by having the multiple benefit of advancing development whilst improving the environment must be actively pursued.

(ii) Assuming that an investment I produces a negative ΔEIE, i.e., there is a reduction in the emissions intensity of the economy, it is obvious that the ratio (ΔEGHG/I) is the emissions reduction "bang" per investment "buck" and that this effectiveness of investments is determined by (ΔEIE/I), the reduction in the emissions intensity of the economy achieved per $ of investment.

2. Choice of the Mix of Technologies for Emissions Reduction

The magnitude of the reduction in the emissions intensity of the economy achieved per $ of investment, i.e., (/\EIE/I), depends upon the technologies for emissions reduction. The generic types of these technologies are

- o Improvements in End-use Efficiency
- o Reduction of Emissions Intensity of Energy Production
- o Encouragement of beneficial shifts in energy carriers and transport modes
- o Reductions of emissions of other GHGs
- o Transmission and Distribution Efficiency
- o Emissions Reduction at the point of End-use
- o Combatting deforestation
- o GHG sequestration

What merits consideration here is the guideline that investments should be directed towards that **mix** of technologies which achieves the maximum reduction in emissions for a given investment.

The identification of this mix requires information on

(i) the emissions reduction per $ of investment, (/\EGHG/I), or its reciprocal, viz., the unit cost of emissions reduction, (I//\EGHG), for the various technologies, and

(ii) the magnitude of the emissions reduction, /\EGHG, achievable with these technologies.

If this information were available, one could construct a cost-emissions-reduction-technology (CERT) curve as shown below in Figure 1. The area under such a CERT curve would yield the total investment that is required for the mix of technologies to achieve a given emissions reduction. And since the X-axis measures the emissions reduction, /\EGHG, one could either identify

- o which mix of technologies is likely to achieve the maximum emissions reduction, /\EGHG, for a given total investment I or

- o how much total investment is required to achieve a given magnitude of emissions reduction /\EGHG.

Figure 1: Cost-Emissions-Reduction-Technology Curves

```
        |                         T3
I//\EGHG|                       -----
        |              T2
        |             ----------
        |      T1
        |     ---------
        |
        |----------------------------------------
              Emissions Reduction /\EGHG
```

3. Classes of Technologies to be included in CERT curves

What characteristics should technologies possess before they are considered for inclusion in the CERT curves?

One approach is to restrict attention only to already-available technologies that have penetrated (or are ready to penetrate) the economy because they are technologically proven and economically viable and the market environment for them is conducive.

But, even among these technologies there are two categories.

Figure 2: CERT Curves for Different Technology Classes

```
                    ------------------------------  GEF(II)    Achievement

                  Investment I        T4       WB
Investment I"         GEF(II)      ----------  T5'   GEF(I)
                         WB      T3          ----------
              ----          -----      T4'
                        T2          -----
                  ----------      T3'
  I/          T1             -----
 /\EGHG       ----         T2'   GEF(I)
                       ----------
                T1'
              ---------
         -------------------------------------------------------
               Emissions Reduction /\EGHG, /\EGHG', /\EGHG"
```

Firstly, there are the technologically proven, economically viable and market-worthy technologies T_1, T_2, ..., T_i, that make up the country's growth portfolio because they promote the economic growth of a country -- they may be designated the WB technologies since they are eligible for support by mainstream financing such as the World Bank. The resulting CERT curve labelled WB in Figure 2 shows how much emissions reduction, /\EGHG, can be achieved with ready technologies for which the technologies, costs and markets are right and conventional financing mechanisms are operating.

But, there are also the technologies T_1", T_2", ..., T_i", -- designated the GEF(II) class -- that would be excluded from a country's portfolio even though they confer global environmental benefits because they are costlier than the WB category. The resulting CERT curve labelled GEF(II) in Figure 2 shows that /\EGHG" > /\EGHG, i.e., more emissions reduction can be achieved with GEF(II) technologies compared to the WB technologies.

Then, there are potentially-available technologies that promise even greater global environmental benefits than the already-available technologies, but they are handicapped by the fact that the technology, economics and market are not yet "right" but can be made "right".

The GEF(II) class of technologies would be excluded from mainstream financing on cost grounds and therefore require special funding mechanisms such as GEF. Mainstream financing mechanisms are also unlikely to support the GEF(I) class of technologies; they require special funding mechanisms to make them technologically proven, economically viable and to make the market environment conducive. In such a situation, the special funding mechanisms such as the GEF must assist the GEF(I) class of technologies and make them implementable by assisting them to realize their full technical, economic and market potential.

If one considers for inclusion in the CERT curves those technologies T_1', T_2', ..., T_i', of the GEF(I) class for which the technology, economics and market are not yet right -- but can be made right -- then the resulting CERT curve labelled GEF(I) in Figure 2 would reveal the reduction in the emissions of greenhouse gases, ΔEGHG', that is possible if the technology, economics and market are made right with the relevant investment. In general, one would expect that, for the same total investment I, the more advanced technologies T_1', T_2', ..., T_i', ... would yield a much greater emissions reduction, ΔEGHG', (cf. the CERT curve labelled GEF(I) in Figure 2) than the emissions reduction, ΔEGHG, for the WB-class of technologies T_1, T_2, ..., T_i,.. In other words, the GEF(I) curve corresponds to a lower investment I' (than the I for the WB curve) for the same emissions reduction, i.e., the adoption of GEF(I)-class of technologies will reduce costs significantly.

APPENDIX 2: PRIORITIES FOR GEF FUNDING FOR REDUCING & LIMITING GHG EMISSIONS*

1. Introduction

The two basic approaches to the reduction of the concentration of greenhouse gases (GHG) in the atmosphere are

(1) reduction of the emissions of GHG, and
(2) sequestration of the GHG.

In the context of global warming, it is necessary to consider the following GHG: CO_2, CH_4, CFCs, tropospheric O_3, and N_2O. The radiative forcing and lifetimes of each of these gases is different but it is possible to attribute to all the GHG carbon-equivalent emissions.

2. Emissions of Greenhouse Gases and Energy Services

The total emissions of greenhouse gases and the total services provided by the energy system can be described with the following expressions:

$$\text{EMISSIONS} = \text{POP}^n \times \frac{\text{GDP}}{\text{POP}^n} \times \frac{\text{En. PROD}^n}{\text{GDP}} \times \left[\frac{\text{EMISSIONS}_p}{\text{En. PROD}^n} + \left\{\frac{\text{En.CONS}^n}{\text{En. PROD}^n} \times \frac{\text{EMISSIONS}_c}{\text{En.CONS}^n}\right\}\right]$$

$$\text{SERVICES} = \text{POP}^n \times \frac{\text{GDP}}{\text{POP}^n} \times \frac{\text{En. PROD}^n}{\text{GDP}} \times \frac{\text{En. CONS}^n}{\text{En. PROD}^n} \times \frac{\text{SERVICES}}{\text{En.CONS}^n}$$

where EMISSIONS is the total emissions, POPn, the population, GDP, the Gross Domestic Product, En. PROD^n, the energy production, EMISSIONS_p, the emissions on the energy production side, En. CONS^n, the energy consumption, EMISSIONS_c, the emissions on the energy consumption side, and SERVICES, the total energy services.

It is also possible to define an emissions/services ratio

$$\text{EmSR} = \frac{\text{EMISSIONS}}{\text{SERVICES}} = \frac{\left[\frac{\text{EMISSIONS}_p}{\text{En. PROD}^n} + \left\{\frac{\text{En. CONS}^n}{\text{En. PROD}^n} \times \frac{\text{EMISSIONS}_c}{\text{En.CONS}^n}\right\}\right]}{\frac{\text{En. CONS}^n}{\text{En. PROD}^n} \times \frac{\text{SERVICES}}{\text{En.CONS}^n}}$$

This expression can be further simplified in terms of $\text{EI}(\text{PROD}^n)$, the emissions intensity of production, $\text{EI}(\text{CONS}^n)$, the emissions intensity of consumption, T&D EFF^y, the transmission & distribution efficiency, and EU EFF^y, the end-use efficiency:

$$\text{EmSR} = \frac{\text{EI}(\text{PROD}^n) + [\text{ T\&D EFF}^y \times \text{EI}(\text{CONS}^n)]}{\text{T\&D EFF}^y \times \text{EU EFF}^y}$$

Suppose that there is a carrier shift such that an energy carrier is replaced with electricity or vice versa, then one has to consider the difference in the values of the emissions/services ratios, $EmSR_b$ and $EmSR_a$, before and after the carrier shift. Then

$$EmSR_b - EmSR_a = \left[\frac{EI(PROD^n) + [\,T\&D\ EFF^y \times EI(CONS^n)]}{T\&D\ EFF^y \times EU\ EFF^y}\right]_b - \left[\frac{EI(PROD^n) + [\,T\&D\ EFF^y \times EI(CONS^n)]}{T\&D\ EFF^y \times EU\ EFF^y}\right]_a$$

Assuming that the product, $T\&D\ EFF^y \times EU\ EFF^y$, remains the same, i.e., $(T\&D\ EFF^y \times EU\ EFF^y)_b = (T\&D\ EFF^y \times EU\ EFF^y)_a$, it follows that

$$EmSR_b - EmSR_a = [1/(T\&D\ EFF^y \times EU\ EFF^y)] \times [\{EI(PROD^n)_b - EI(PROD^n)_a\} + T\&D\ EFF^y \times \{EI(CONS^n)_b - EI(CONS^n)_a\}]$$

If, therefore, $EI(PROD^n)_b > EI(PROD^n)_a\}$ and/or $EI(CONS^n)_b > EI(CONS^n)_a$, it follows that $EmSR_b > EmSR_a$, i.e., the carrier shift will lead to an emissions reduction.

A similar result can be obtained through a change of transport mode, i.e., a modal shift, for example, from truck haulage of freight to rail haulage, passenger transportation from personal automobiles to mass transit systems, etc.

There are two possible objective functions:-

- minimization of the total emissions
- minimization of the emissions/services ratio.

An exclusive focus on the total emissions may lead to a neglect of the imperative need to increase the level of services, particularly in developing countries. So, the problem is to reduce the emissions/services ratio subject to the constraint of increasing the level of energy services and reducing the total emissions.

Based on the above analysis, it appears that there are five basic categories of interventions that can result in a reduction of emissions:

1. Improvement of end-use efficiency [SERVICES/En.CONS^n]
2. Improvement of transmission & distribution efficiency [T&D EFF^y]
3. Reduction of the CO_2-equivalent emissions intensity of energy <u>production</u> [EMISSIONS/En.PROD^n]
4. Reduction of the CO_2-equivalent emissions intensity of energy <u>consumption</u> [EMISSIONS/En.CONS^n]
5. Shift of energy carriers and/or transport modes [$EmSR_b - EmSR_a$]

3<u>Sequestration of Greenhouse Gases</u>

Sequestering carbon in growing forests is a relatively low-cost strategy for offsetting CO_2 emissions from fossil fuel substitution. However, substantially greater benefits can be obtained by combining this sequestration of carbon with utilization of sustainably grown biomass as a energy source to displace fossil fuels.

4List of projects

The above categories of interventions that can result in a reduction of GHG emissions and in sequestration of GHG can be used to develop a list of projects (cf. Appendix 3) that merit consideration for GEF funding.

1. Improvement of end-use efficiency [SERVICES/En.CONS^n]

1.1 Reduction of the energy intensity of the basic materials processing industries
1.2 Efficient motors and drives
1.3 Efficient process heating
1.4 Efficient Lighting
1.5 Efficient Appliances
1.6 Efficient Space heating and cooling
1.7 Efficient Water-heating
1.8 Efficient Irrigation Pumpsets
1.9 Efficiency of Infrastructure
1.10 Land use planning
1.11 Vehicle fuel efficiency

2. Improvement of transmission & distribution efficiency [T&D EFF^y]

2.1 Reduction of T & D losses in electrical grids

3. Reduction of the CO_2-equivalent emissions intensity of energy production [EMISSIONS/En.PROD^n]

3.1 Centralized renewable technologies
3.1.1 Wind Farms
3.1.2 Solar thermal
3.1.3 Hydro
3.1.4 Geothermal

3.2. Decentralized technologies
3.2.1 Fuel cells
3.2.2 Photovoltaics (grid connected or stand-alone)
3.2.3 Cogeneration and stand-alone power generation from biomass
3.2.4 Fossil fuel cogeneration
3.2.5 Small Hydro

3.3 Fossil fuels to renewables
3.3.1 Biomass gasifiers/gas turbines
3.3.2 Using sustainable grown biomass to replace fossil fuels

4. Reduction of the CO_2-equivalent emissions intensity of energy consumption [EMISSIONS/En.$CONS^n$]

4.1 Transport
4.1.1 Emission Controls (e.g., Catalytic converters)

5. Beneficial Shifts of energy carriers and/or transport modes

5.1. Intra-fossil fuel shifts: coal --> oil --> natural Gas
5.1.1 Advanced efficient gas turbine cycles
5.1.2 Natural Gas-fired engine-driven cooling systems
5.1.3 CNG for transport

5.2 Transport modal shifts
5.2.1 Road --> Rail modal shift for freight
5.2.2 Personal --> mass transit shift for passengers
5.2.3 Other modal shifts

6. Sequestration of Greenhouse Gases

6.1 Management of Tropical forests
6.2 Carbon sequestration in growing forests
6.3 Removal/sequestration of CO_2 from fossil fuel systems

7. Combatting deforestation

7.1 Biomass combustion
7.2 Providing incentives for maintenance of forests

8. Reducing non-CO_2 GHG

8.1 Methane
8.1.1 Urban and rural waste treatment
8.1.2 Reduction of leaks in natural gas pipelines
8.1.3 Reduction of flaring/venting of natural gas
8.1.4 Reduction of releases in coal mining
8.1.5 Reduction of agricultural emissions
8.1.5.1 Rice paddies
8.1.5.2 Animals

8.2 Surprises
8.2.1 N_2O from fluid-bed combustion of coal

8.3 Precursors to tropospheric O_3 (CO, NO_x, NMHCs or NMVOCs)

8.4 Long lived CFCs, HFC, HCFCs (reduce lifetimes, energy penalties)

9. Generic

9.1 Performance improvement through management, institutional and policy innovations
9.2 Least-cost planning
9.3 Conversion of energy supply companies to energy service companies (ESCOs)
9.4 New Energy Service Companies
9.5 Independent power companies
9.6 Management of dispersed energy systems
9.7 Industries that manufacture energy efficient products
9.8 Technology transfer
9.9 Assessing technology import versus domestic manufacture
9.10 Training/institution building
9.11 Database development

1. From Criteria to Priorities

Because the list of projects is very large, it is unlikely to be of much use in practice. Hence, it is essential to prioritize the projects.

Ideally, the prioritization can be done on the basis of the cost-emissions-reduction-technology (CERT) curves described in the companion note on the "Criteria for GEF Funding for Reducing & Limiting GHG Emissions". A selection can be made of all the technogies/projects that constitute the mix of technologies that yield the maximum potential emissions reduction for a given investment. Within this mix, the technologies can be ranked according to increasing unit cost of emissions reduction, i.e., decreasing cost-effectiveness. Alternatively, they can be ranked according to decreasing magnitude of (potential) emissions reduction.

To operate this prioritization procedure, it is necessary to have reliable data on the unit cost of emissions reduction and the magnitude of potential emissions reduction of the various technologies. Unfortunately, this data is not readily available in a standardized and assembled form. An urgent task, therefore, is to assemble this data.

In the meantime, the only prioritization that can be done immediately (say, before the end of the Working Group meeting) is that based on synthesizing the priorities assigned by the experts along with the rationale for these priorities.

One can also intiate a process of giving to each project i a score S_i by using each criteria C_j, assigning marks M_{ij} say on a one-to-ten scale, multiplying these marks M_{ij} by an agreed weighting factor w_j and then adding the weighted marks ($w_j \times M_{ij}$) for all the criteria:

$$S_i = Sum_j \, [(w_j \times M_{ij})$$

The projects can then be prioritized on the basis of their scores.

Figure 2: CERT Curves for Different Technology Classes

```
                  ------------------------------  GEF(II)    Achievement

                Investment I        T_4       WB
Investment I"       GEF(II)      ----------  T_5'   GEF(I)
                     WB      T_3           ----------
             -----          -----     T_4'
                     T_2          -----
                  ----------      T_3'
   I          T_1            -----
 /\EGHG      -----          T_2'   GEF(I)
                       ----------
                T_1'
             ----------  Investment I'      /\EGHG      /\EGHG'
         Base                                   /\EGHG"
         ------------------------------------------------------
             Emissions Reduction /\EGHG
```