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REPORT ON GLOBAL WARMING AND ASSOCIATED IMPACTS

(PHASE II)

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GREENHOUSE GAS EMISSIONS AND GLOBAL COMMONS: AN INDIAN PERSPECTIVE

Dr. R.K. Pachauri
Dr. Ligia Noronha
Dr. Ajay Mathur
Ms. Kanishka Nagpal
Ms. Sujata Gupta

The problem of rising concentrations of Greenhouse Gases (GHGs) in the atmosphere focuses sharply on the question of a sustainable globe since it is a result of the range of primary production and consumption activities that make up a modern, industrial, mass society. The first task, therefore, is to establish the causal chain between activities and consequences. This exercise will illustrate the fundamental link between the vision of the good society, that is the basis for our policy choices, and the consequences of GHGs that follow from these choices and that are the cause of so much consternation. Once the list of offending activities has been satisfactorily established, and this involves a major interdisciplinary scientific exercise, then the issue of political will, i.e., what should be done, by whom, and to what extent, gains relevance.

The significance of political will will become evident when we assume that the scientific aspect of establishing the causal chain between activities and consequences of GHGs has been demonstrated and as a result, therefore, there is need for both individual and collective responses to not only prevent these dreaded consequences but to also remedy those that have already come about [1]. This question of appropriate responses has two aspects: (a) the political aspect where choices are made on a variety of grounds and (b) the technical aspect where choices are made purely in terms of their instrumental effectiveness. The political aspect in turn has two component parts: the normative component, where the moral grounds for adopting particular activities are forwarded, and the expedient component, where the prudential and the practical grounds for the recommended responses are considered. This paper considers both the nomature and expedient components of a political response; the Indian technical response has been discussed in an earlier TERI position paper [2].

Historical Overview

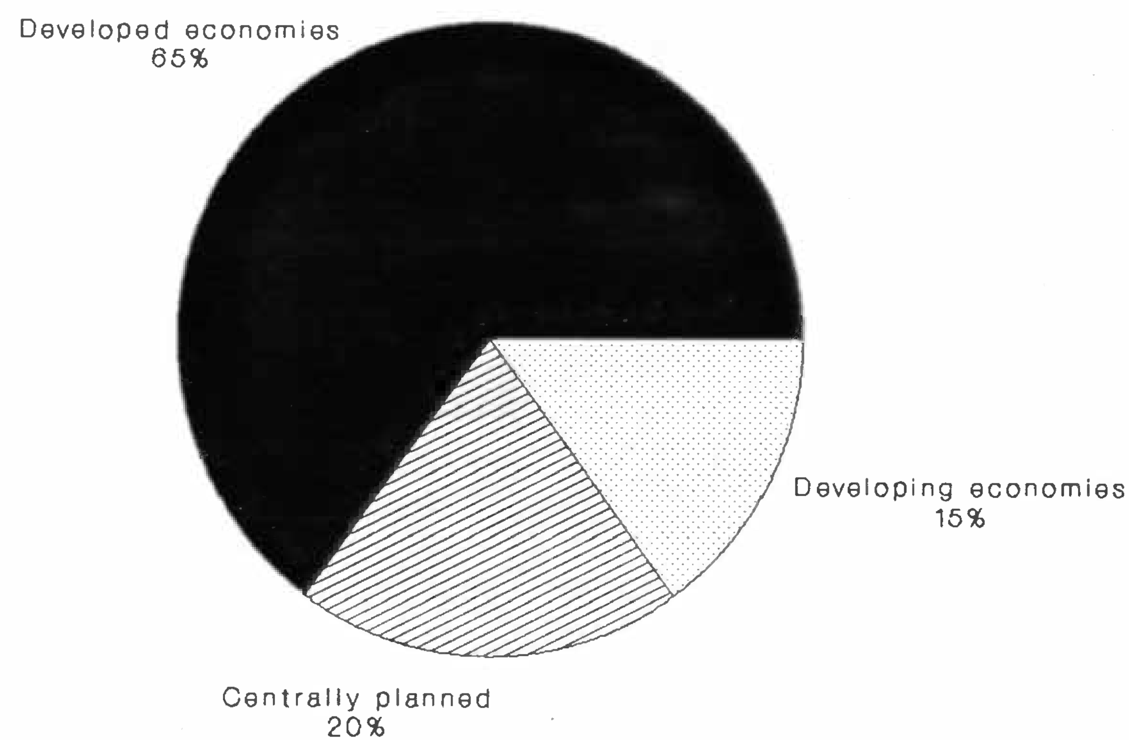
The problem of GHG concentrations in the atmosphere is an instance of pollution of the global commons. The historical explanation for this is that a minority of countries have, since the Industrial Revolution, pre-emptively utilized a large part of global environmental resources, particularly the atmosphere and the oceans, which have served as assimilators of the residues of the processes of production and consumption. These less visible resources were, and remain, essential to industrial growth. Since they were shared in common it was to everyone's interest to pollute them rather than to conserve them because they involved little apparent cost. These first comers to the Industrial and the Technological Revolution, by virtue of being first in the race, operated under few limit restrictions. That is, they were in a position where the calculation of the actions of agents need only be in terms of the narrow consequences for these agents themselves rather than the broader consequences for society as a whole. Being first comers they operated in an intellectual world committed to the belief that while wants are infinite, these can be satisfied by increasing total production infinitely. In this, technology was seen as the solution to any growth-induced limitation problem.

The choices made, and the pattern of growth adopted, over time, brought into existence major interests that have today developed a stake in the continuation of present growth pattern and are, therefore, difficult to politically oppose, e.g., the coal industry, the oil companies and the automobile industry.

This pre-emption of global resources and their overuse, in terms of the number that has benefited from such use, has been a result of the lifestyles (in the broader sense) that have been adopted by the developed world, lifestyles made possible because of their growth-oriented, energy-driven, resource-intensive development strategies. Fossil fuels - coal, oil, natural gas - were the main components of the energy base that fuelled such strategies. These energy sources are also those most responsible for the increased CO_2 concentrations in the atmosphere. The large use of fossil fuels in the period since 1870 by the developed countries has resulted in disproportionately larger CO_2 emissions relative to the rest of the world. Figure 1 gives the region-wise cumulative emissions of CO_2 in this period.

This particular situation of overexploitation of environmental resources has been exacerbated because: (a) the

Fig.1 Regionwise cumulative share of CO_2 emissions 1870-1986



Source: Pachauri et al (3)

"common property" nature of the resource, (b) the condition of "abundance", and (c) the "public good" nature of the atmosphere.

In the pursuit of growth and profits, each nation was concerned only with the scale of its own operations and resource use and in the process, therefore, ignored the combined effect of such action by many nations on the resource in question. At that time, it "made sense" for each nation to allow the residuals of its production and consumption processes to be pumped into the atmosphere. The cumulative effect of the actions of individual nations and entitles, however, has been the production of an outcome that is proving ruinous for all.

Such behavior is not seen as a problem as long as the resource, in question, is in abundance and is operating under frontier conditions, i.e., when the supply is far in excess of the demands put on it. Similarly, free access to global resources was not perceived as a problem as long as the agents using such resources were few and the environment had the ability to process these demands without major adverse changes. But as these demands increased, both in the number of polluters and in the quantum of pollution, the potential for conflict amongst users tended to rise. "Abundance of a resource" is thus a static concept, and cannot be used in a dynamic, historical sense, because as more nations make demands on the resource, its capacity to accommodate these demands will be greatly reduced to the detriment of all.

Further, the inability to establish property rules in the case of the atmosphere and the oceans makes it difficult to price these resources. As a result, the greenhouse gases that are currently polluting the atmosphere were pumped at a rate that exceeded the amount that would have been pumped if a price had been attached to the assimilative function of the atmosphere. Thus, the inability to corall the atmosphere by property rights makes it difficult to internalize the social costs of such actions.

The problem of GHG concentrations, hence, points to the ecological and political-economic interdependence of territorial zones within a global mosaic. This makes imperative the need for responses and initiatives that are communitarian rather than individualistic in character. Such initiatives will have to consider the dilemma, on the one hand, that the growth-oriented, energy-driven, development strategies of the developed world are still attractive for the developing world because of their observed effectiveness in attenuating poverty and improving the standard of living and, on the other hand, that the pursuit of such strategies today involves a far greater damage to the environment, than when the growth of the developed economies took off, because of its reduced absorptive capacity. The environment today is passing through a perilous period, where the choices and actions of today have irreversible and detrimental effects for the future. How then do the developing countries choose between protecting the global commons and pursuing their own growth imperatives?

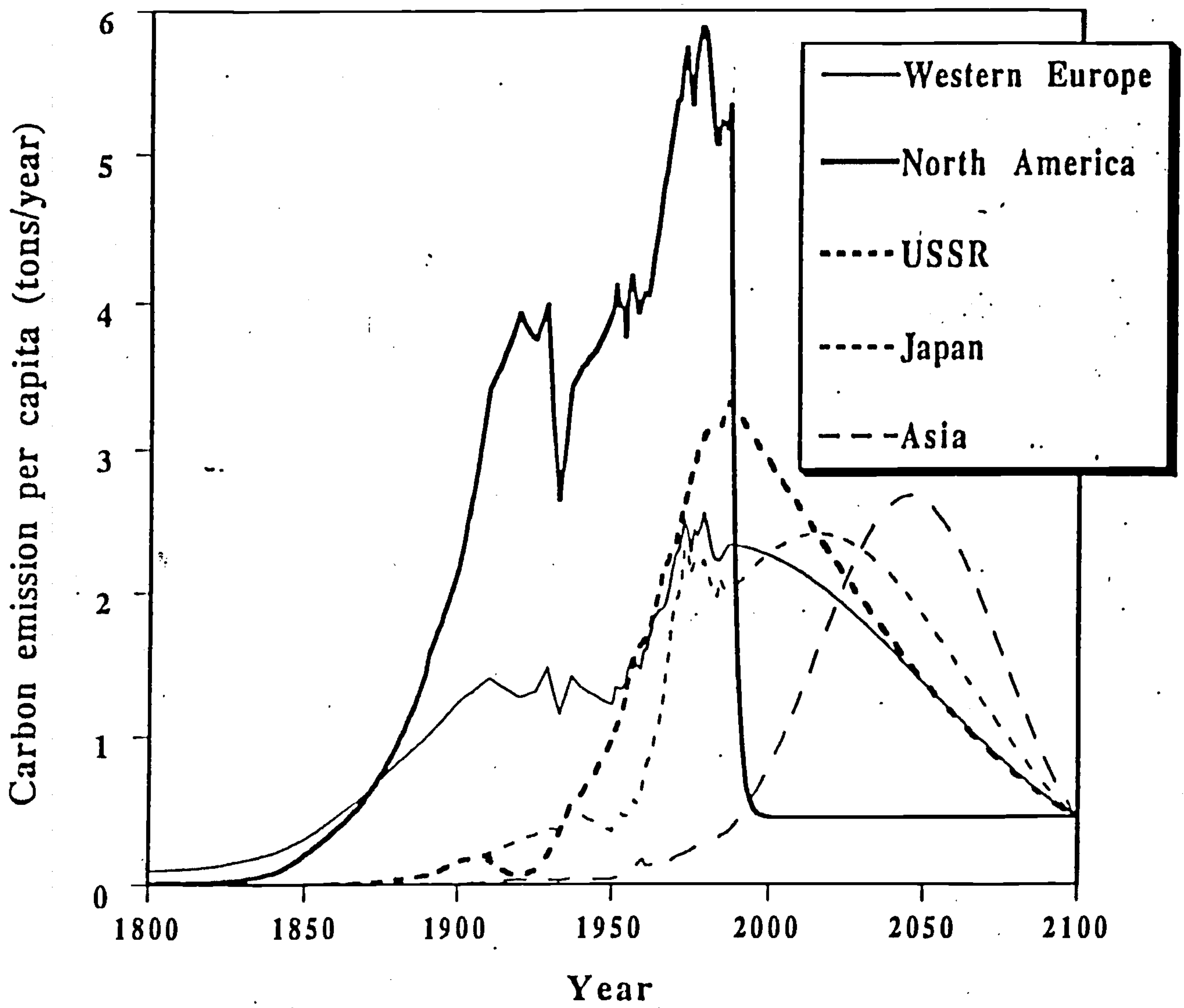
Equity in Responses to Climate Change

The predominant role of the developed economies in reducing the absorptive capacity of the atmosphere to GHGs constrains the growth choices available to developing countries now, as well as to future generations for several centuries to come. The concepts of inter-generational and inter-generational equity suggest that the developed countries owe an "environmental debt" to the larger global community [4]. This approach can help in determining how the remaining absorptive capacity may be fairly shared and used sustainably. This concept forms the basis of the normative component of a political response.

Figure 2 shows the per capita carbon emissions from different regions of the world since 1800. North American emissions have been considerably higher than those from other parts of the world ever since 1870. During this period, on an individual basis, they have used nearly fifteen times as much as of the global commons (atmosphere and oceans) as have residents of Asia.

Sustainability demands that we stabilize carbon emissions, and equity demands parity in per capita emissions from all regions of the world. Such a scenario is shown in the right half of Figure 2 where hypothetical future per capita emission profiles are plotted. These ensure

Fig. 2 Historical and hypothetical future carbon emission profiles



Source: Grubler (5)

stabilization of global carbon dioxide concentration at 600 ppm by 2100, and attainment of a globally uniform per capita emission level of 0.5 tonnes of carbon per annum. This scenario would necessitate an immediate 90% reduction in North American emissions which then remain constant at 0.5 tonnes per annum. Developing countries are allowed further increases in per capita emissions in this scenario to 2 tonnes carbon per year in 2050, which would enable them to ensure provision of minimum energy supplies to all their citizens, as well as expand their economies so as to raise standards of living. Beyond 2050, energy efficiency measures and deployment of renewable energy technologies would drive the per capita emissions steadily downwards so as to reach the 0.5 tonnes carbon per annum level by 2100.

A range of scenarios of the type depicted in the right-half of Figure 2 are possible based on different apportionments of future emissions. The three underlying principles in establishing these apportionments have to be:

(i) Stabilization of atmospheric carbon dioxide concentration at a given level by a given date.

(ii) Attainment of uniform level of per capita carbon emissions (consistent with the stabilized level of atmospheric CO_2 concentrations) globally.

(iii) Reflection of past emission patterns and present level of development in the future emission profiles so that countries which have been disproportionately larger carbon emitters have to achieve larger reductions and developing countries are allowed increases to a level that ensures energy sufficiency with energy efficiency.

The expediency component of a political response might dilute the large reductions required of North America. The allowed emissions may be translated into, "tradeable quotas", by which the U.S.A. for example, could purchase emission quotas from developing countries rather than invest in reducing into own emissions to its own allowable emission level. The long-term problem that could be generated by such a system is one of a, "quota debt crisis", faced by developing countries in the future when they find their own emissions increasing but have already traded away their emission quotas. A middle course could be to assign quotas and allow trading only on an annual or short-term (2-3 years) basis. The tradeable quota system would ensure flow of resources to developing countries, at least in the short term. In the medium and long term, the developed countries might find it economically more attractive to reduce their own emissions to allowable limits, thereby reducing the tradeable value of the quotas held by developing countries.

A more robust approach, though much more difficult to implement, would be the setting up of a Multilateral Fund to assist the developing countries in limiting carbon emissions. The fund size would be linked to developing country requirements, and contribution would be proportional to the country's, "carbon debt", i.e., the level by which cumulative per capita carbon emissions have exceeded the emission level at which atmospheric CO_2 concentration would stabilize. This would necessitate country-by-country assessments of CO_2 limitation costs, as well as identification of the incremental component of these costs due to an International Climate Protocol.

The two most important components of the technical response to developing countries such as India, and those which have potential political underpinnings, are the role of forests and afforestation while defining emissions, and the span of GHGs included in the Protocol. Vegetation absorbs carbon dioxide, and afforestation is, therefore, a means of decreasing net emissions. This option is not available to many countries (including several in the developing world) who could be led to treat forests as global commons. However, this is a country-specific problem, and hence should be addressed as a technical response, rather than a political one.

The threat of global warming is due to the emission of a host of GHGs: primarily carbon dioxide, methane, nitrogen oxides, and CFCs. Consequently, any Protocol to limit GHG emissions must consider all gases, rather than any one alone. There is a feeling that initially limitations should apply to CO_2 alone: this places India at a disadvantage since it has large methane emissions while the share of developed country emissions is much smaller. Consequently, at a later date, when methane is included in the Protocol, there would be no obligation on the part of the developed countries to assist India in limiting methane emissions. A multi-gas approach would be to India's advantage as the high CO_2 emissions from developed countries more than offset the high methane emissions from India, especially on a per capita basis.

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A REAPPRAISAL OF WRI'S ESTIMATES OF GREENHOUSE GAS EMISSIONS

Dr. R.K. Pachauri
Ms. Sujata Gupta
Ms. Meeta Keswani

In the current debate on global warming and climate change and strategies and measures to stabilise the earth's atmosphere, estimates of emissions in the past and future projections would provide critical information for forthcoming negotiations. Any convention to limit the emissions of greenhouse gases (GHGs) would also use as a starting point the quantification of past and future emissions. It is, therefore, necessary that the developing countries carry out detailed analyses of their emission levels and ensure that accurate and unbiased information is disseminated to mobilise worldwide public opinion in support of equity issues of relevance to the third world.

The World Resources Institute(WRI) in its recent report "World Resources, 1990-91" has directed considerable attention to this topic. By providing estimates of emissions of GHGs it has identified the 50 largest contributors to global warming. Although the WRI report is being widely publicised and frequently quoted, the numbers contained in this study ought to be treated with great caution.

The approach adopted by the WRI in calculating the "Greenhouse Index", by which different nations are ranked, is highly questionable. It is a scientifically established fact that the heating potential of a gas depends not only on its radiative forcing (the capacity of the gas to absorb heat within a particular wavelength range) but also its residence time. For example, in the case of two gases with the same radiative forcing but with different lifetimes, the gas with a longer life will have a greater potential to cause warming, because it would be active for a longer duration. Recognising this fact, the Inter-governmental Panel on Climate Change (IPCC) has arrived at the global warming potential(GWP) for different GHGs by taking the decay function of carbon dioxide (CO_2) and radiative forcing over a period of hundred years as the numeraire (integration time horizon = 100 years).

The WRI report has ignored the residence time of different gases, thereby giving gases like methane (CH_4), with a high radiative forcing but a shorter lifetime, an unduly high relative GWP compared to CO_2. Hence, their ranking is unacceptable, as it is biased against the developing countries, which are normally low emitters of CO_2 as opposed to the industrialised nations. In this note an attempt has been made to correct this inconsistency inherent in the WRI estimates.

Furthermore, the data for India on CH_4 emissions from paddy fields (wet rice) and for CO_2 emissions from deforestation are grossly overstated. These numbers are also rectified in this note.

In making our calculations, the following assumptions made by WRI are maintained as they are based on factual measurements and facilitate a comparative analysis for different nations.

The WRI report states, "... The increases in concentrations total less than the amount emitted by human activity, so sinks for both CO_2 and CH_4 must have also increased.

The total emission of CO_2 caused by human activities in 1987 was about 8.6 billion metric tons(expressed in terms of total carbon content of the CO_2), but the total in the atmosphere increased by only about 3.7 billion metric tons. Methane emissions in 1987 were about 255 million metric tons but the atmosphere had a net increase of only about 43 million metric tons. (WRI, therefore) ... attributes these atmospheric increases to countries in proportion to the fraction of the total CO_2 and CH_4 emissions that can be assigned to each".

This is tantamount to each country getting an equi-proportionate share in the sinks even if it emits a larger proportion of GHGs. Thus, it is not logical to consider the sources and sinks together. However, for analytical purposes, the above mentioned WRI approach is not modified at present. Further work is intended in the future, challenging the basic WRI approach and presenting an alternative.

Thus only 43 percent of CO_2 and 16.9 percent of CH_4 emitted will be added to the atmosphere for all nations.

<u>IPCC GWP:</u> The IPCC has computed the relative GWP of different GHGs in CO_2 equivalent on the basis of a 100 years time horizon. These estimates, for some of the gases, are presented in Table 1 below.

Table 1. Global warming potential per tonne of gas (in CO_2 equivalent)

	IPCC	WRI
Carbon Dioxide	1	1
Methane	21	70
CFC-11	3500	6400
CFC-12	7300	6400

Deforestation

The extent of deforestation in India has been grossly overstated in the WRI report. Outdated estimates have been relied upon despite the availability of more recent assessments. The WRI has used the National Remote Sensing Agency (NRSA) data published in 1984 for the period 1972-75 and 1980-82. The NRSA estimates suffered from many inadequacies and did not represent the correct forest cover in the country. An assessment made by the Forest Survey of India (FSI) for the period 1981-83 showed wide divergence from the NRSA estimates.

The Ministry of Environment and Forests had recently directed the two national agencies to reconcile their figures (referred to as the reconciled 1987 figure). The FSI made a second assessment for the period 1985-87 (referred to as the 1989 figure). The new (1989) assessment, shown in Table 2 gives a forest cover of 64.01 million hectares compared to the earlier reconciled figure of 64.20 million hectares approximately. Thus, during the last 4 years the annual rate of forest loss works out to only 47,500 hectares.

Table 2: Deforestation in India

Sl. No.	Category	1987 Assessment (Sq. Km)	1989 Assessment (Sq. Km)	Change in Area (Sq. Km)
1.	Dense forest (crown density 40% and over)	3,61,412	3,78,470	(+) 17058
2.	Open forest (crown density 10% to less than 40%)	2,76,583	2,57,409	(-) 19174
3.	Mangrove forest	4,046	4,255	(+) 209
		6,42,041	6,40,134	(-) 1907

Source: [1]

The 1987 and 1989 assessments may not be comparable owing to:

(i) difference in scale that is, 1:1 million in 1987 and 1:250,000 in 1989

(ii) spatial resolutions-79 m using Multi Spectral Scanner in 1987 and 30m using Thematic Mappler (TM) in 1989.

In this regard, The State of Forest Report 1989, (FSI) mentioned, "... However, the intensive ground truth verification made by FSI has resulted in sorting out the real differences from those which are on account of technical reasons, to a substantial degree".

Thus, in our analysis we take the figure of 47,500 hectares as the average annual deforestation over the period 1981-83 and 1985-87.

Based on the ground inventories FSI has calculated the average growing stock of Indian forests to be 65 cubic meters per hectare[1]. The weight to volume ratio of wood is taken as 750 kilograms per cubic meter, air dry and with 10% moisture content. On this basis the growing stock of wood works out to be 48750 kilograms or 48.75 tonnes per hectare. The carbon content of wood is taken to be 45 percent. Table 3 shows the calculations by TERI using these estimates and WRI's published figures for India assessing CO_2 from deforestation.

Table 3: Carbon dioxide emissions from deforestation in India

		TERI	WRI
1.	Area deforested (000 hectares)	47.5	1,500
2.	Growing Stock per hectares (tonnes/hectare)	48.75	209*
3.	Wood burnt due to deforestation (000 tonnes)	2316	313300*
4.	Carbon released from deforestation (with 45 percent carbon in wood) (000 tonnes of carbon)	1042	141,000
5.	Additions to atmospheric CO_2 (43 percent of release) (000 tonnes of carbon)	448	61,000

* Calculated.

It is important to note that in making the above calculations TERI has assumed that the entire wood from deforested areas is burnt. In reality, a large proportion of the wood is used for various industrial purposes such as for manufacturing of furniture and railway sleepers, erection of buildings and other civil work, etc. rather than as fuelwood. However, no data is available in this respect and we have preferred, therefore, to use the higher assumption of all timber from deforestation being burned.

Secondly, a perusal of Table 2 shows that the area under dense forests has registered an increase of 4.7 percent, whereas most of the deforestation has taken place in open forest areas which showed a decline of 6.9 percent. This implies that more carbon has been fixed through increased forest activity than released by deforestation. However, given the paucity of data no accurate quantification is possible, and we have, therefore, excluded the increase in this afforestation from our computations.

Lastly, the amount of afforestation resulting from roadside plantation of trees & shrubs is also not included owing to lack of information.

The above three factors clearly indicate that the level of deforestation considered by TERI & the associated CO_2 emissions are essentially an overestimation of the actual level. Yet, nevertheless TERI's estimates, backed by reliable data, are far lower than those of WRI.

Methane from wet rice cultivation

Lately, several attempts have been made in India to measure the methane flux from paddy fields by the National Physical Laboratory [3,4,5]. On the basis of one such set of measurements, made for estimating the total emissions from paddy fields in the Indian sub-continent, Dr A.P. Mitra, Director General, Council for Scientific and Industrial Research, India, concluded that the contribution from rice fields in India is in the range of 3-9 Tg of methane per annum.

There are a number of factors like the temperature of the soil, pH value of the soil and the use of fertilizers, which determine the methane emissions from inundated rice fields. However, even at the upper limit of the above mentioned range viz. 9 Tg per annum methane emissions from rice cultivation in India would amount to only half the WRI estimate of 18 Tg. Therefore, the WRI numbers are certainly overestimated in this respect also.

Methane from livestock

Methane emissions from the stomachs of ruminants are directly related to its body weight, level of nourishment, type of diet, particularly, the cellulose forage content and the population of methane producing bacteria.

The National Dairy Research Institute, Indian Council of Agricultural Research, measured methane production to be in the range of 12-20 litres per day for sheep and goats, and 70-85 litres per day for cattle and buffaloes.[6]

Multiplication of these emission factors by the most recent livestock population number [7] gives nearly 5790 thousand tonnes of methane from livestock in India. WRI has overestimated this figure by 73 per cent at 10,000 thousand tonnes.

Table 4 : Methane emissions from ruminants

Type of animal	Methane emission per capita		Population (millions)	Total animal CH_4 emissions (000 tonnes)
	litres/day	kg/annum		
(1)	(2)●	(3)	(4)●●	(3)x(4)
Bovine	70	18.3*	192.45	3530
Buffaloes	85	22.3*	69.78	1554
Sheeps	16	4.2*	48.76	204
Goats	16	4.2*	95.25	399
Pigs	-	1.0**	10.07	10
Camels	-	58.0**	1.08	63
Horses and ponies	-	18.0**	0.90	16
Donkeys and mules	-	10.0**	1.16	12
Total				5788

Source : * Calculated using a density of 0.718 kg/m^3 for methane [8]
** [9]
● [6]
●● [7]

Conclusions

On the basis of the above computations, it can be concluded that the estimates made by WRI for India are inaccurate, particularly for carbon dioxide from deforestation and methane emissions from rice cultivation and the stomachs of ruminants.

The total global warming potential of different gases (in carbon dioxide equivalent terms) has been recalculated by using the IPCC numbers for all the countries. Table 4 below shows the revised rankings and percentage contributions to the greenhouse gas build-up for the first 15 nations juxtaposed with WRI's erroneous rankings published in their 1990-91 Report.

Table 5: Greenhouse ranking for the top 15 contributors

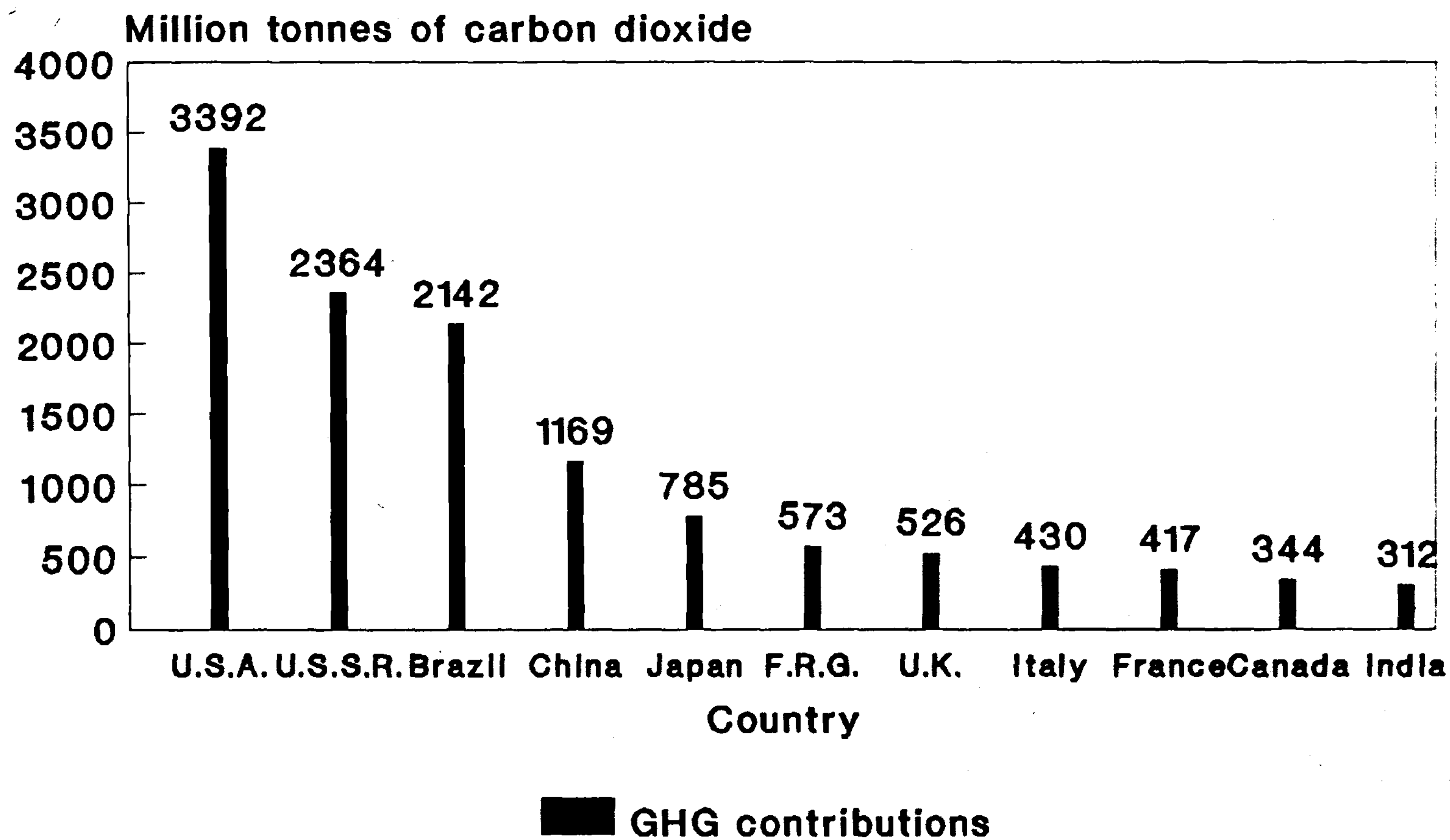
Country	TERI		WRI	
	Greenhouse Index Rank	Percentage Contribution	Greenhouse Index Rank	Percentage Contribution
USA	1	17.5	1	17.6
USSR	2	12.2	2	12.0
Brazil	3	11.0	3	10.5
China	4	6.0	4	6.6
Japan	5	4.0	6	3.9
German Federal Rep.	6	3.0	7	2.8
United Kingdom	7	2.7	8	2.7
Indonesia	8	3.4	9	2.4
Italy	9	2.2	11	2.1
France	10	2.2	10	2.1
Canada	11	1.8	12	2.0
India	12	1.6	5	3.9
Poland	13	1.4	15	1.3
Myanmar	14	1.3	14	1.3
Spain	15	1.3	16	1.2

The above analysis shows that India, placed fifth by the WRI study, now ranks twelfth. This revised ranking follows the WRI's basic approach to which many may find fault since it ignores the concept of equity issues. But this issue will be addressed in a later study to be released by TERI.

According to TERI's estimates, India's share in global warming declines from 3.9 percent to 1.6 percent using WRI's methodology, but using more reliable and unbiased data for India.

The WRI estimates for other developing countries like Brazil and China may also be inaccurate and it is likely that

Net atmospheric increase in greenhouse gases (carbon dioxide equivalent)



Using IPCC GWP numbers & an integration time of 100 years their shares and rankings may be very different as compared to those shown by the erroneous WRI study. In fact, Jose Goldemberg, currently Minister for Science & Technology in Brazil, and also a member of the WRI Board went public in July 1990 by publishing a letter in the New York Times which challenged WRI data for deforestation in respect of Brazil.

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ADAPTIVE STRATEGIES FOR INDIA IN THE PERSPECTIVE OF CLIMATE CHANGE

Dr. Ajay Mathur
Mr. O.N. Kaul
Ms. Amrita N Achanta
Ms. Sujata Gupta

Global warming is expected to result in the following climate changes by the middle of the next century:

(a) Increase in mean annual temperature of the order of 0.5 to 3°C, and increase in soil moisture by 5% (in winter) to 10% (in summer).

(b) Increase in discharge of glacier-fed rivers by 8 to 50% during peak flow periods.

(c) Increase in mean sea level by 20 to 55 cms.

The possible impacts of these changes would increase energy demand because of higher temperatures and because of the adaptive control strategies adopted, increased soil erosion and flooding due to increased peak flows of glacier-fed rivers, decreased biomass productivity, and submergence of coastal areas.

The consideration of climatic change response strategies presents immense difficulties as the information available to make correct policy options is inadequate because of the scientific uncertainties regarding, (i) the magnitude, timing, rate and regional consequences of potential climatic change; (ii) how effective specific response options or groups of options would be, in actually averting potential climatic change; and (iii) the costs, effects on economic growth, and other economic and social implications of specific response options or groups of options.

A prudent approach to climatic change would have to consider both Limitation and Adaptation Strategies, because even if concerted efforts are made, now, to limit emissions of GHGs through Limitation Strategies, some Adaptation Strategies would still be necessary. This is, firstly, due to the fact that climatic changes may be already under way as a result of past emissions into the atmosphere, and secondly, by the climatic changes that may occur before the options adopted under Limitation Strategy become effective.

It would, therefore, be necessary to consider Limitation and Adaptation strategies as an integrated package wherein the options adopted in the two cases compliment each other so as to minimise time and costs, should a significant adverse climatic change occur. In view of the scientific uncertainties and the difficulties of foretelling the effects of global warming,it is not possible to chalk out any precise strategies to counter such effects and we have to be content with some general strategies at present.

Adaptive strategies should, in general, aim at

(1) minimizing energy demand

(2) afforestation so as to minimize soil erosion and maximize absorption of surface water by the soil

(3) changes in cropping patterns and agricultural practices so as to minimize disruption to foodgrain production

(4) minimization to economic disruption due to sea level rise.

These strategies are discussed in some detail in the following pages.

Management of Energy Demand

Increased mean annual temperatures would lead to an increase in the demand of energy for refrigeration and cooling, as well as a decrease in the efficiency of most thermal and electrical devices owing to the higher ambient (sink) temperatures. However, increasing energy supply to meet this increased demand would lead to enhancement of the global warming phenomena owing to the increase in CO_2 emissions. Consequently response strategies would necessarily aim at increases in the efficiency of supply technologies and development of non-fossil fuel based technology (e.g., renewables). Similarly, energy efficiency and energy conservation on the demand side would be an essential component of the adaptive strategies. Efficiency in all sectors will have to be increased; major benefits accrue due to efficiency improvements in the vast and inefficient domestic energy sector and in the grossly inefficient transport sector.

Domestic Sector

The domestic sector accounts for nearly 40% of the total energy consumption in India, and about 80% of the total demand in rural areas. In the rural areas, 70-90% energy is consumed for cooking and water heating. Hence energy efficiency improvements in cooking play a critical role in managing rural energy demand. The main fuels used in rural areas for cooking are wood, crop residues and dung cakes; all of which are mostly collected. Presently in India, nearly 85 million rural households depend on biomass fuels for cooking.

These fuels are used in wood stoves with average efficiency of 8%. A major efficiency measure is the promotion of improved stoves.

The national programme on improved chullahs (NPIC) was initiated by the department of Non-Conventional Energy Sources (DNES) in December 1983. It is estimated that 4 million improved stoves were installed till 1988 at a cost of Rs. 287 million. Evaluation status have indicated that 50-80% installed improved stoves are being used at present with average fuel savings of about 25%. Given these statistics and an ultimate penetration of about 90% in the rural sector, some 70 million more improved stoves can be installed. These would result in an overall biomass saving of the order of 20 million tons. At present costs, this improved stove dissemination programme require an investment of nearly Rs. 7 billion in a comparatively short period of time.

In urban areas, biomass fuels continue to be an important source of household energy. However, unlike in rural areas where most of the fuel required is collected by the poor, the poor in urban areas have to purchase the biomass required. These fuels are burnt in low-efficiency devices as in the rural sectors. In recent years, the urban poor are being squeezed in the energy market since it is becoming increasingly difficult to obtain adequate amounts of biomass fuel, and the supply of kerosene is also inadequate, particularly in small towns. It is essential that firewood and imported kerosene are replaced as cooking fuel for the urban poor. An alternative is the development of smokeless coal-based fuels such as briquette or gasifier systems for producing coal gas. At present, briquetting and gasifier technology in India is obsolete and expensive. These technologies need to be imported and indigenously developed. At the same time, emphasis on the development of high efficiency briquettes stoves also need to be taken up. Because of the higher end use efficiency, coal briquettes and gas use would lead to a decrease in the total CO_2 emissions as compared to those from biomass burning.

Refrigeration and Air Conditioning

Increased temperatures would lead to increased demand for refrigeration and air conditioning. At present, efficiency in this sector is lower than international norms, but improving. However, the phasing out of CFCs would lead to a decrease in energy efficiency, but nevertheless a 50% decrease in energy consumption is possible with the technology available in the international market today. This would imply additional investment of the order of 25-40%. It is imperative that efficient technologies are imported in the country at the earliest.

Transportation Sector

Transportation sector is the most inefficient energy consuming sector in the Indian economy. Average energy efficiency is less than 20%: road transportation efficiency is of the order of 15% and that of rail transportation between 24 and 30%. In addition, road transportation also emits nitrogen oxides a major green house gas - whose control has to be addressed in response strategies as well. Currently, international road transportation efficiencies are of the order of 30%, and improving. This implies that the state of the art technology can already reduce energy consumption in this subsector by as much as 50%. It is estimated that the price of individual energy-efficient cars and trucks would increase by 10 to 25%. In the case of rail transportation, efficiency improvement to 50% is possible.

In India, the major decrease in transportation energy requirement would result from a shift from private to public transportation. This implies the establishment of an efficient, reliable and comfortable public transportation system in urban areas. The high capital cost of public transportation systems has been a major deterrent in their establishment. It is estimated an efficient, reliable and comfortable public transportation systems for the Delhi would cost about Rs. 7,000 crores. Other specific suggestions include the development of urban buses (present buses are built on the chassis of long-distance trucks), and research and development towards commercialisation of electric vehicles, especially solar powered electric vehicles.

Industry

Industry (including thermal power generation) consumes about 45% of the total energy consumed in India. The average efficiency of thermal power generation (which alone amounts for about 50% of the energy used in this sector) is 28%. Of the other 50% of the energy consumed in this sector, roughly two-thirds is in the form of thermal energy (primarily for steam raising), while the remaining one-third is electric power (primarily for electrical drives such as motors). The average boiler efficiency is roughly 60%, while average motor efficiency is about 70%. Internationally the efficiencies for thermal power generation, steam -raising boilers, and electrical motors are in excess of 35%, 75% and 85% respectively. In general therefore, increases of the order of 7 to 10% are possible.

In the case of thermal power generation, advanced boiler design as well as new coal utilization technologies are required. In addition, better operation and maintenance of existing stock, and retrofits on aged boilers can lead to an increase of 2 to 3% in the overall efficiency. The major constraint is the lack of capital for renovation and retrofits, as well as for normal operation and maintenance. This is related to the pricing policy, as well as capital availability. International technology transfer in the long terms would be desirable for the power sector. In the short term availability of cheap capital for renovation and retrofits would go a long way in increasing the efficiency. However, the most important single factor is to place the electrical utilities on a sound fiscal basis.

Most steam raising boilers in India are 20-30 years old, and utilize outdated (stoked boilers) technology. However, in recent years, several Indian companies have started manufacturing and selling high efficiency fluidized bed boilers with efficiencies in excess of 70%. It is estimated that nearly two-thirds of new orders for boilers in India are for fluidized bed boilers. In spite of the success of fluidized bed boilers in India, penetration is slow owing to replacement of a boiler only after it is totally decrepit. It would accelerate the process of penetration if policies for the availability of cheap capital for the installation of energy-efficient boilers are introduced.

Technology transfer in the area of energy-efficient motors is also essential. The design and materials of construction of these motors needs to be upgraded so as to achieve energy savings.

Afforestation

Forests, because they offer a greater carbon storage capacity than either grasslands or croplands, represent an important opportunity for any mitigation strategy. They also offer additional social benefits such as erosion control, aesthetics, wildlife habitats, watershed protection, pollution control, reducing temperatures and the like.

Forests are net source or sinks for carbon depending upon net changes in biomass. To the extent forests expand through either the existing forests becoming more productive by better management or establishment of new plantations, additional atmospheric carbon is sequestered, thereby moderating the built up of atmospheric CO_2.

Improved management of existing forests would result in increased biomass and hence in the sequestering of additional carbon. However, establishment of large scale plantations would be required to offset a significant portion of the additional CO_2 currently accumulating in the atmosphere. Although this endeavor may seem monumental in scope, it is probably the do-able and may be least costly to deal with global warming over the next few decades.

In view of the above the following policy options are suggested.

1/ Identify major flow routes for flood water of snow-fed rivers and carry out afforestation along these routes. This afforestation should be carried out in a manner which reduces the kinetic energy of water flow and increases its traverse time across any terrain. This will minimize soil erosion and maximize replenishment of ground water reservoirs.

2/ Promotion of research and development activities in species development technologies - selection and breeding and biotechnology which will make plant species more adaptive to changing climatic conditions. Existing tree and shrub species will have to be scanned for resistance/tolerance to GHGs with a view to use these species on large scale in critical areas.

3/ Development and implementation of policies to reduce deforestation and forest degradation and to ensure the health and sustainable management of existing forests in order to enhance CO_2 sinks.

4/ Establishment of large scale plantations (preferably of mixed species) in conjunction with a dramatic decrease in the rate of deforestation, to be used as a mechanism to postpone the build-up of CO_2 and thus delay global warming.

5/ Conversion of marginal agricultural land to forests to enhance CO_2 sequestering.

6/ Reduction in forest biomass burning through improved and proper fire management practices and widespread use of alternative sources of energy to fuelwood.

7/ Encourage agroforestry and development management systems which may be less vulnerable to climatic change. Agriculture and forestry plans should be integrated in such a manner so that it reconciles the demands on our forests for expansion of agriculture.

8/ Develop inventories, data bases, monitoring systems and catalogues of the current state of resources and resource use and management practices through an all India coordinated schemes for making a realistic assessment of the problem and for arriving at realistic policy options to be adopted.

9/ Strengthening and enlarging protected natural areas and establishing conservation corridors to preserve biological and genetic diversity and to enhance the adaptation prospects for various ecosystems.

10/ Increased emphasis on the development and adoption of technologies - silvicultural and management and genetically improved trees - which may increase productivity or efficiency per unit area of land, consistent with sustainable economic growth and development to foster more carbon fixation, besides affecting high genetic diversity and high productivity.

11/ Increased promotion and strengthening of resource conservation and sustainable resource use, especially in highly vulnerable areas.

12/ Developing management system whereby the local population and resource users gain a stake in conservation and sustainable resource use.

13/ Increasing forest protection through incorporation of strategies for fire, insects and diseases into future management plans and through development of silvicultural practices and stress management strategies.

Agriculture

Climate change is likely to result in a significant impact on agriculture and related areas. It is important to consider what measures could be taken so as to respond to such a change. These measures would increase the ability of society and the ecosystem to adapt to a climate change. Given the scientific uncertainties of potential climate change, uncertainty regarding effectiveness of strategy adopted and uncertainty of both economic and social implications, policy decisions remain difficult.

While considering options, some of the aspects which must be considered are justifiability of adoption of option for reasons other than climate change, cost effectiveness, flexibility, sustainable development and the particular needs of the developing countries.

Some of the options which could be considered are:

Plant Genetic Improvement

According to the General Circulation Model predictions, it is expected that apart from an increase in carbon dioxide concentrations, a temperature rise of 1-4.5°C is likely. An average increase of 8-11% precipitation is expected globally, although the distribution of rainfall will be uneven.

This change in global climate will have an effect on agriculture due to:

1) increase in CO_2 concentration
2) changes in temperature
3) changes in the amounts and distribution of rainfall in different regions and in different seasons
4) changes in river flow
5) submergence or salinization of coastal areas and
6) increased ultra-violet radiation.

Such a climate change is likely to necessitate the development of cultivars which are better suited to the altered climatic conditions.

Development of heat and drought tolerant cultivars should be included in plant breeding objectives for the region. Plants which show a greater yield in response to higher CO_2 levels must be identified. Development of rice varieties with longer grainfilling period at temperatures 1-2°C warmer than present day temperature needs, to be undertaken by plant breeders.

Since salinization and flooding of coastal areas is one of the likely adverse effects of global warming, research to develop salt resistant varieties of important crops grown in these regions should be a priority area.

The germplasm collections for most of the important crops and the number of varieties tested under the All India Coordinated project trials are large. Suitable varieties may therefore, be available and identified for their suitability in the event of a climate change.

Water Resource Management

Development of methods of water storage and conservation, particularly in the case of areas where rainfall is likely to be lower. This must be considered although most general circulation models predict an average 8-11% increase in precipitation, rainfall distribution is likely to be uneven.

The impact of global warming is likely to be less if water and fertilizer inputs are increased. An extension of areas with irrigation and higher fertilizer use must be an integral part of the plan.

Future Research

The effect of global warming on the monsoons is uncertain since temperature is one of the sixteen different factors which influence the south-west monsoon. The study of this area is of major importance. An increase in riverflow particularly of the snow-fed rivers, due to increased melting of snow, and greater precipitation in some regions is likely to lead to the necessity for flood control in several regions.

Minimization to Economic Disruption Due to Sea Level Rise

The various stages in adaptation of a response to sea level rise (SLR) are:

1. Assessing the vulnerability of an area to a sea level rise. As it is not possible to protect the entire coast line, it is necessary to prioritize areas which are more vulnerable to a SLR. For this an index of vulnerability can be established.
2. Research of the various adaptative options. Possible adaptation measures to combat sea level rise include

- construction of sea wall/flood barriers
- national flood insurance programme
- construction of reservoirs to combat increased salinity
- abandonment of developed regions in low lying area
- relocation of population away from vulnerable areas
- protection of coastal eco-systems and development of marine environments.

3. Choosing between alternative responses. The rise in the relative sea level and the consequent impacts are region or location specific. Thus, the response strategy is site specific and will depend on the resources, socio-economic characteristics of the region. For example, for Bangladesh, given the pressure of population on land, relocation of population may prove to be a difficult measure.

For a developing country like India with limited resources to adopt technical responses, natural resources to mitigate the effect of a potential, sea level rise seems a more viable option. Thus, eco-systems in the inter-tidal zones need to be taken into account when alternative development strategies are being considered.

4. Implementing the response. This will require a strong institutional set up and new/modified legislative measures.

Strategies for coastal zone management can be classified as follows:

1. Retreat - shift of people and eco-systems landward
2. Accommodation - continued habitation of the threatened area through adaptative measures like construction of flood shelters, buildings on elevated platforms, development of fishponds instead of agricultural fields, promotion of salt resistant species etc.
3. Protection - protecting land from sea by constructing dikes, bulkheads etc., through beach nourishment and nurturing of the natural vegetation. Marine environments besides having a commercial role also protect the coast by reducing the vulnerability of the coast line to erosion, storm surges and coastal flooding.

Wetlands. Regulatory protection alone cannot achieve the goal of zero net loss of coastal wetlands. A retreat strategy where the wetlands are allowed to migrate landwards as the sea level rises should not allow permanent development or 'hardening' of uplands in which wetlands would be expected to migrate if sea level rises.

There are two aspects to coastal zone planning:

1. An assessment of area which should be allowed to develop; those which should be sterilized; those which should be armoured by structural defenses and those which should be up- graded because of existing conditions that increase its vulnerability to sea level rise.
2. An assessment of coastal activities which are more vulnerable to sea level rise. It is necessary to assess the coastal dependency of human activity and classify them as "essential", "most desirable", "desirable", "beneficial", or "immaterial". Only "essential" activities should be promoted in threatened zones. "Most desirable" to "beneficial" should be evaluated, using the conventional criteria of feasibility, and cost effectiveness. For example, in a coastal area prone to greater erosion from SLR, the policy should be avoid siting a coast-dependent activity which is vulnerable to erosion but is not amenable to adaptation or retreat.

Thus it is necessary to consider the interaction between marine ecosystems and coastal uses and assess their impacts in the event of a SLR. The problem is then one of a choice between an optimal mix of preservation and development (or planned exploitation). The criterion of maximization of net present value of social returns from the area should be used to arrive at a decision.

Types of Adaptive Options

One can identify three main categories of responses to the SLR problem. These could be titled : (a) Biological (b) Technical (c) Institutional. Biological responses would concentrate on developing alternatives to lost or threatened resources and habitats or on enabling the development of species that are more tolerant to the changed environment. The emphasis in this set of responses would be to assist the ecological systems to adapt to an environment that changes faster than their natural ability to adapt to it. Technical responses are essentially engineering solutions and involve the building of structures that will protect the coast from submergence and overtopping. Such responses involve both 'hard' and 'soft' engineering options. Dikes, groynes, bulkheads, etc. are examples of the former. Beach nourishment is an example of the latter. The third category of responses is institutional. As information about SLR increases, coastal users and uses are allowed to respond to the potential threats either naturally or by the use of legal and policy means.

STRATEGIES FOR LIMITING CARBON DIOXIDE EMISSIONS IN INDIA

Dr. Ajay Mathur
Mr. A.N. Chaturvedi
Mr. G. Sambasivan
Dr. Veena Joshi
Mr. Chandrashekhar Sinha
Dr. Kapil Thukral
Dr. Ranjan Kumar Bose

Executive Summary

Total energy supply in India is of the order of 400 million tonnes coal-equivalent (MTce), of which about 170 MTce is biomass-based fuels. The total carbon dioxide emissions from fossil fuels are about 92 million tonnes of carbon (MTC). Fossil fuel supply is expected to rise to about 340 MTce by 2000, implying CO_2 emissions of 136 MTC. Biomass fuel consumption is expected to rise to about 250 MTce.

The potential for reducing primary energy consumption, principally of CO_2-producing fuels, without reducing end-use services is examined in this paper. Three strategies have been investigated: increase in energy utilization efficiency (in the electricity, industrial transport, agricultural and domestic sectors); larger deployment of renewable energy technologies; and afforestation. For each strategy, the realistic potential realizable by 2000 AD has been assessed. The projected implementation of each strategy already planned has been identified. The cost of implementing the incremental potential (i.e., the cost of extending implementation beyond the planned level to the realistically realizable level by 2000) is then calculated, along with the reduction in CO_2 emissions due to incremental implementation. For each option, the specific cost of CO_2 removal is also calculated. Table S-1 lists the incremental potential, the incremental cost, and the specific CO_2 removal cost for each option.

The largest potential for reducing CO_2 emissions is through afforestation; the specific cost of emission reduction by afforestation (Rs.2,160/T carbon) is also amongst the lowest of all the options identified. The energy-related options have specific reduction costs ranging from 686/T carbon to Rs.4,34,783/T carbon. The cost curve for annual CO_2 emission reduction is generated by arranging the options in ascending order by specific reduction cost, and then adding incremental potentials to obtain cumulative reduction, and adding incremental costs to obtain cumulative cost. The resulting cost curve for energy-related options is shown in Figure S-1. The sharp gradient of the curve represents the largest quantum of reductions of the order of 40 million T of carbon per year, which are obtained by investments of about Rs.600 billion.

Table S-1: **Incremental potential and cost of various CO_2 emission reduction options**

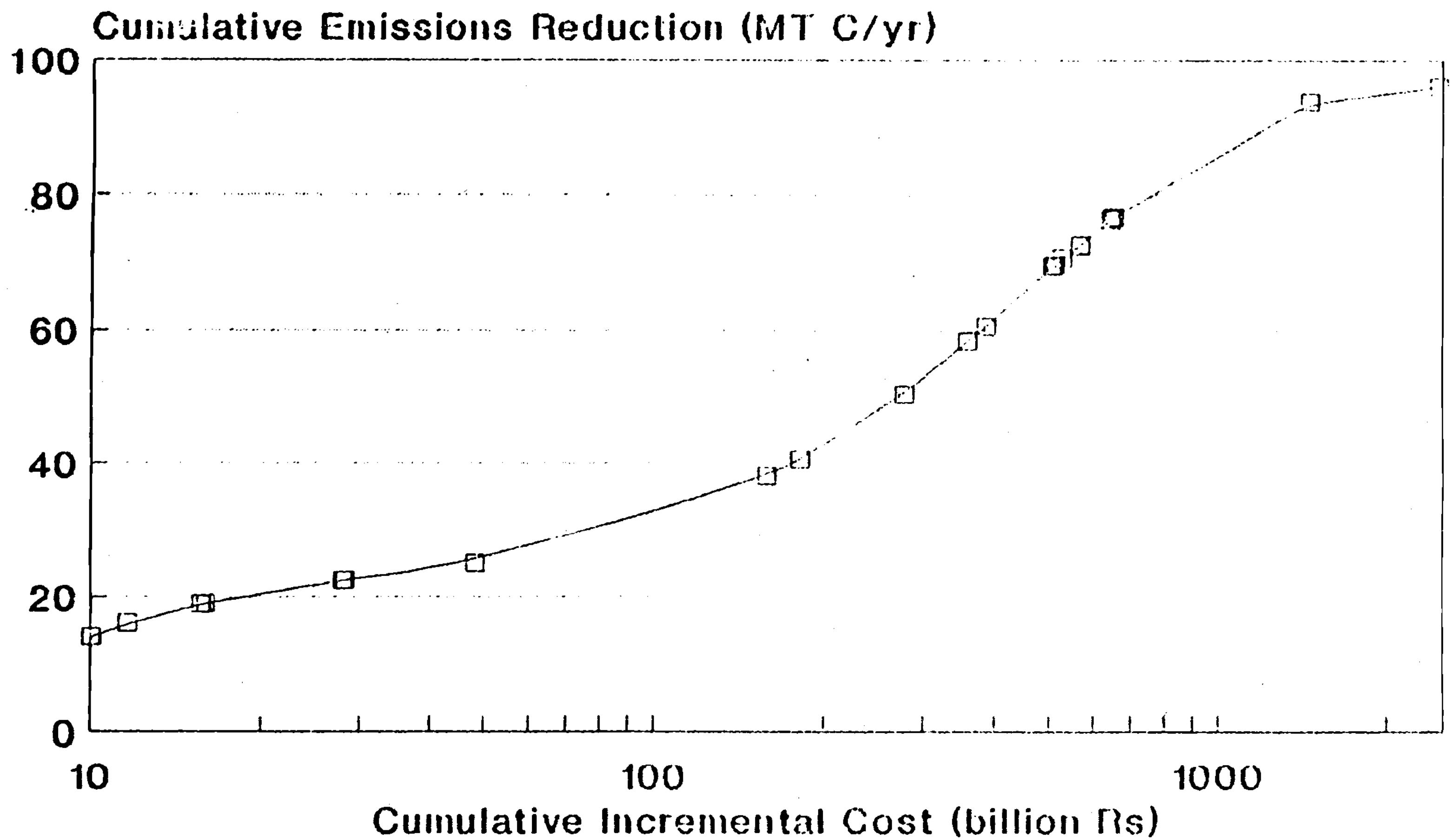
	Incremental Potential for Reduction in CO_2 Emissions (MT of Carbon)	**Incremental Cost (Billion, Rs.)**	**Specific Cost of CO_2 Reduction (Rs./T Carbon)**
1. **Increase in Energy Utilization Efficiency**			
1.1 Electricity Sector			
* Electricity Generation			
- Coal Washing	14	9.6	686
- Replacement of Coal TPS by Gas Combined Cycle TPS	2.2	28	12,727
* Transmission & Distribution			
- Reduction in T&D Losses	9	120	13,333

Contd...

Table 5-1 Contd..

1.2 Industrial Sector			
* Improved Housekeeping	2.8	4	1,429
* Installation of Energy-Efficient Equipment, and Better Instrumentation & Control	3.5	12	3,428
* Upgradation of Technology	2.5	20	8,000
1.3 Transport Sector			
* Enhanced Urban Public Transport			
- Increasing Bus Fleet	0.7	13	18,571
- Metro Rail Systems	2.3	1,000	4,34,783
* Enhanced Rail Freight Movement	4	185	47,059
1.4 Agricultural Sector			
* Pumpset Rectification	10	95.7	9,570
1.5 Domestic Sector			
* Improved Firewood Chulha	2	2	1,000
* Improved Lighting			
- Replacement by Tube Fluorescent	2.5	22.5	9,000
- Replacement by Compact Fluorescent	13	110	8,462
2. Deployment of Renewable Energy Technologies			
2.1 Low-Medium Temperature Solar Devices			
* Solar Cookers			
- Family Size	0.12	0.3	2,500
- Community	0.02	0.07	3,500
* Solar Hot Water System			
- Domestic	0.01	0.34	34,000
- Industrial	0.07	1.22	17,429
* Solar Timber Kiln	0.01	0.11	10,900
* Solar Au Heaters/Dryers	0.02	0.09	4,400
2.2 High Solar Power Generation			
* Line Focussing Steam Cycle Power Plant	0.18	2.99	1,661
2.3 Electricity from Other Renewables			
* Biomass	7.8	80	10,256
* Wind	3.7	75	20,270
* Small Hydro	2.0	40	20,000
* Sewage Sludge	0.08	1.25	15,625
* Distillery Effluent	0.22	4.90	22,720
* Municipal Solid Waste	0.25	5.33	21,320
* PV Pumps	0.01	1.56	1,56,000
* Windpumps	0.05	0.91	18,200
3. Afforestation	35	210	600

Cost Curve for Energy-Related CO2 Emission Reduction Options
Target Year: 2000 AD



Each symbol represents the complete exploitation of an emission reduction option

Figure S-1

This paper aims at providing the elements of strategies for the limitation of carbon dioxide emissions from India. The working principle is to identify the broad strategies; the extent to which these strategies can be realistically adopted; an analysis of the constraints to their implementation; identification of incremental inputs that would be required for their implementation to the realistic level and of the institutional mechanisms that would be most suitable for channelling these incremental inputs; and the reduction in carbon dioxide emissions that would occur with the implementation of the strategies as compared to the no-strategy scenario. For all quantification, a time horizon of 2000 has been adopted.

Three broad strategies are identified here: increase in energy utilization efficiency; deployment of renewable energy technologies; and afforestation. The requirements and impacts of each of these strategies are discussed in the following in the perspective of the working principle outlined above. This paper is an analysis of strategies: both energy savings and consequent carbon dioxide emissions, as well as investments required are quantified only to a first approximation. A detailed study of each strategy would required to obtain precise numbers.

Increase in Energy Utilization Efficiency

The total "useful" energy consumption in India today, i.e., the amount of energy which is ultimately available for the doing desired work, is about 70 million tonnes coal-equivalent (MTce), whereas the total energy supply is in excess of 400 MTce[1]. The overall thermal energy efficiency

[1] P V Sridharan and A Mathur, Sustainable Management of Coal Resources in India, TERI, New Delhi, 1990.

the economy is, therefore, only 17.5%. In part, this low efficiency is because of the large amount of biomass supply (approximately 170 MTce) which is utilized at an efficiency of about 8%[2]. However, biomass fuels apart, even commercial energy utilization efficiency is less than 25%. There is ample scope, therefore, for substantial increases in energy efficiency.

The Inter-Ministerial Working Group on Energy Conservation setup in 1981 estimated that an economy-wide saving of 25% in commercial energy consumption seemed possible[3]. Appendix I lists a summary of the measures suggested by them, the savings expected, and the investments required. Twenty five percent savings in the industrial sector, 20% in the transport sector, and 30% in the agricultural sector were projected with a total investment of Rs.5140 crores (at 1982 prices).

This section re-examines the potential for energy conservation in the Indian economy, and evaluates the incremental resource requirements to implement these conservation measures.

<u>Electricity Sector</u>

Electricity Generation : The installed electricity generation capacity at the end of 1989-90 was 62,534 MW and the total generation during the year was about 233 TWh. Approximately

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[2] <u>Towards a Perspective on Energy Demand and Supply in India in 2004/05</u>, Advisory Board on Energy, Government of India, New Delhi, 1985.

[3] Report on Utilization and Conservation of Energy, Inter-Ministerial Working Group on Energy Conservation, Government of India, New Delhi, 1983.

67% of the installed capacity is thermal which contributes over 70% of the total electricity generated[4]. The efficiency of coal conversion in Indian thermal power stations (TPS) is low: the average gross conversion efficiency is 28%, and the average net efficiency is about 25%[5]. Figure 1.1-1 shows the gross efficiency - installed capacity profile. More than 70% of the TPS installed capacity operates at efficiencies below 30%, and 25% of capacity operates at efficiencies even below 25%. The present design gross efficiency is about 32%, and the system-wide design average would probably be 31%. Currently, worldwide, design efficiencies are similar (about 35%), but operating efficiencies are close to the design values. Enhancing TPS performance so that the operating efficiency approaches the design efficiency would increase their power output (at the same coal input rate) by nearly 15%: implying that CO_2 emissions per kWh generated would decrease by nearly 12%.

Some of the power generated in a TPS is utilized to run plant auxiliaries, such as coal grinding mills, air blowers, ESP, etc., and some power is lost in transformation (to transmission voltage), switching, etc. Presently, at the national average, about 10% of the power generated in a TPS is used internally[5]. Consequently, the net conversion efficiency is 90% of the gross conversion efficiency. Decrease in in-plant consumption would, therefore, also result in a reduction in specific CO_2 emission (kg carbon emitted per kWh delivered at TPS busbar).

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[4] TERI Energy Data Directory and Yearbook, 1989, Tata Energy Research Institute, New Delhi, 1990.

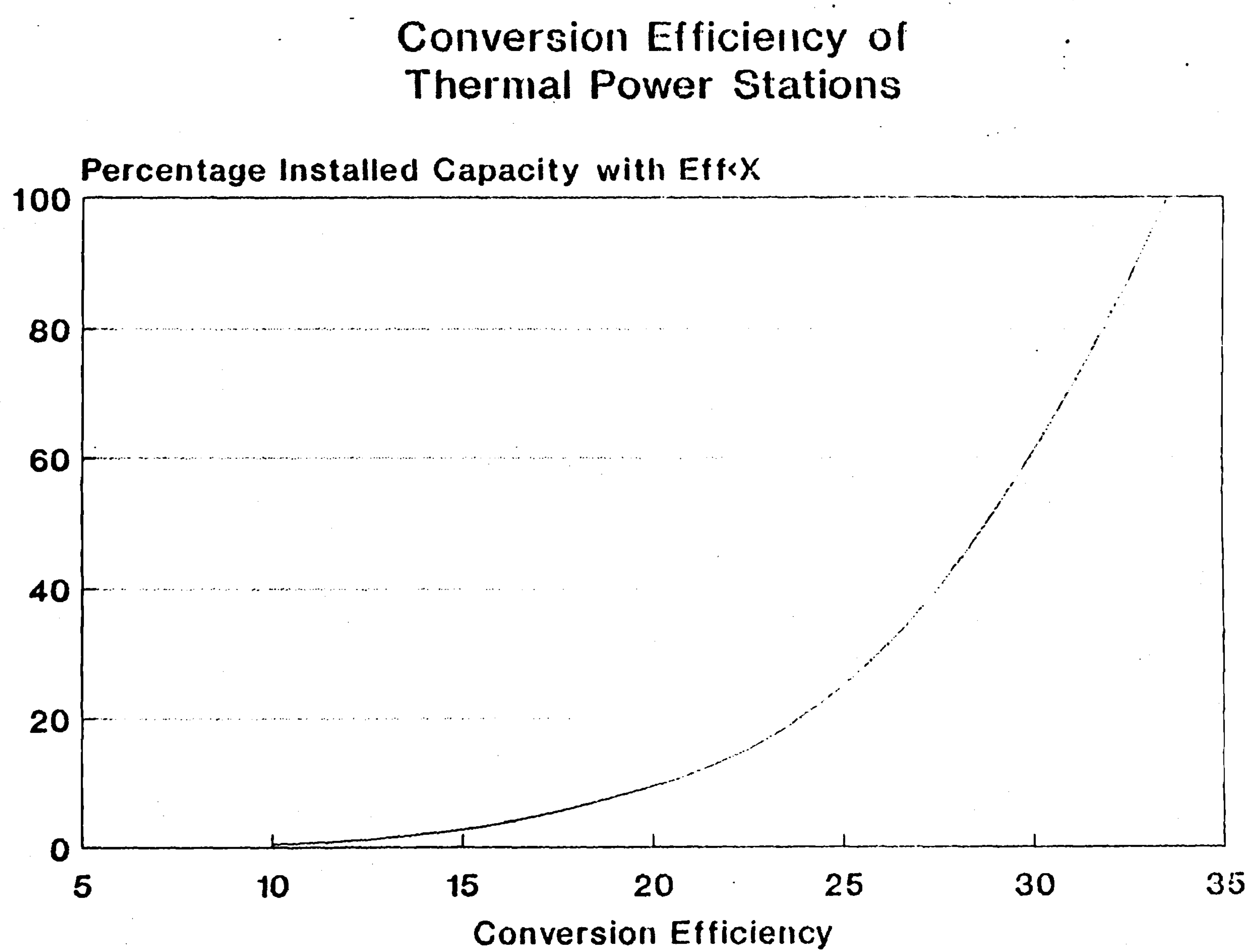
Conversion Efficiency of
Thermal Power Stations
Percentage Installed Capacity with Eff<X
100
80
60
40
20
0
5
10
15
20
25
30
35
Conversion Efficiency

Figure 1.1-1

The principal cause for low TPS efficiency is poor coal quality & poor maintenance & upkeep. High-ash coal, by itself, does not lower efficiency (in fact, boilers burning high-ash coals have the same design efficiency as those burning low-ash coals)[5]. However, coal supplied to TPS is largely from open-cast mines and has a lot of non-coal material (principally shale and rock) mixed with it. This results in poor combustion, as well as in high power requirement for grinding. Washing coal before it is supplied to TPS would greatly reduce the non-coal matter that travels with it. Boiler efficiency with washed coal rises to about 89.5%[6], and in-house electricity consumption reduces from 10 to 8% of gross generation[7].

Considering that the average TPS boiler efficiency is about 77%[8] and average in-house electricity consumption is 10%, washing coal alone would increase net efficiency by 18.8%, i.e., net efficiency would increase from the current 25% to a value of 29.5%. The specific CO_2 emission would fall from 0.29 kgC/kWh to 0.24 kgC/kWh.

There are no washeries for non-coking (power grade) coal in India. The principal reason for their absence in the

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[5] Public Electricity Supply, All India Statistics, General Review 1986-1987, Central Electricity Authority, Government of India, New Delhi, 1990.

[6] Report on Trial of Benefication of Non-Coking Coal from Nandan Washery at Satpura Thermal Power Station, National Productivity Council, Calcutta.

[7] Report on the Committee to Evaluate Benefication of Non-Coking Coal for Thermal Power Stations, Planning Commission, Government of India, New Delhi, 1988.

[8] Based on boiler efficiency test carried out by the Central Electricity Authority.

lack of capital to set them up. A washery for a 1040 MW TPS costs Rs.320 million at present prices (Rs.260 million at 1987 prices)[7]. The total potential for efficiency upgradation (by 18.8%) is judged to be 45% of the total TPS installed capacity, i.e. the percentage of capacity with gross conversion efficiency between 20 and 30% (see Figure 1.1-1). This works out to a total capacity of 18,850 MW. In addition, washeries for future TPS coal supplies would also be required. Official demand projections for future capacity requirements are high, but we think that total coal-based electricity generation capacity would be about 70,000 MW in the year 2000. This implies capacity addition of about 28,000 MW between 1990 and 2000. We judge that the washed coal would continue to be 45% of total coal supplies to TPS; consequently washeries for supplying coal to 31,500 MW of TPS would be required. This implies a capital requirement of Rs. 9,600 million tonnes. The annual CO_2 emissions due to coal combustion in TPS would decrease from 94 million tonnes carbon to 80 million tonnes carbon.

Substitution of coal by gas to the extent possible would also reduce CO_2 emissions. Current plans for gas-based TPS call for an addition of 77,745 MW during 1990-95. Additions during 1995-2000 would probably be about 10,000 MW. Apart from these plans, all the gas presently flared off the West coast could be utilized for power generation in West India which would release an equivalent amount of coal. Currently, over 2.5 billion cu.m of natural gas are flared in the Bombay High basin annually[4]. This gas could generate about 12 TWh of electricity which implies an installed capacity of about 2200 MW of gas-based combined cycle TPS, or an equivalent 2,500 MW coal-based TPs using 8.5 MT of coal per year. The installation of 2,200 MW of gas-based combined-cycle capacity would cost Rs.28,000 million, and would result in CO_2 emissions reduction of 2.2 million tonnes of carbon annually.

Transmission and Distribution

Transmission and distribution (T&D) losses in the Indian power system are estimated at 22%[4]. However, owing to the practice followed by some State Electricity Boards (SEBs), of diverting a certain portion of non-technical/commercial losses towards unmetered power supply to agricultural consumers, the actual T&D losses may be somewhat higher. The Committee on Power[9] recommended a somewhat realistic target of reducing T&D losses to a level of about 15% by the year 2000. Of course, little has been done in this direction so far. In fact, percent T&D losses increased until the mid-1980s and have remained fairly stable since then (see Table 1.1-1).

Table 1.1-1 : T&D losses(%)

1970-71	17.5
1976-77	19.8
1982-83	21.1
1985-86	21.7
1987-88	21.5

Source: (i) CEA, Public Electricity Supply, All India Statistics (General Review), Various Issues.
(ii) CMIE, Current Energy Scene in India, July 1989.

[9] Report of the Committee on Power, Planning Commission, Government of India, New Delhi, 1980.

In order to identify suitable strategies to reduce T&D losses, it would be necessary to know the level of T&D losses taking place at various voltage levels in the T&D system. On the basis of available information, reasonable estimates can be made, and are presented in Table 1.1-2 below.

Table 1.1-2 : Percentage Losses at Various Line Voltages

	% Losses		
	Line	Transformation	Total
EHT (66 kV and higher)	4.0	0.5	4.5
33 kV	3.0	1.0	4.0
11 kV	6.0	1.0	7.0
45 volts	5.5	2.0	7.5
Total	18.5	4.5	23.0

It is apparent from Table 1.1-2 that a major portion of the losses take place at 11 kV and lower voltage levels. These also include non-technical losses, arising from under-recording in meters (most mechanical meters tend to slow down with age), meter tampering, defective meters, and pilferage etc. Losses arising from the latter three factors may be reduced with more care in testing and replacement of meters in time, and strict enforcement of laws to ensure that meters do not get tampered and that electricity theft does not take place. Also, a coordinated programme of periodic meter-testing and recalibration needs to be introduced. It is understood that some utilities have established meter-testing laboratories, but their achievements and performance levels need to be upgraded.

We can reasonably assume that out of 23% T&D losses, technical losses amount to 15% and non-technical losses including pilferage etc. 8%. In order to arrive at "order-of-magnitude" estimates of additional T&D investment requirements to reduce losses to 19% by the end of the 8th FYP period, it can be reasonably assumed that (i) non-technical losses reduce from the present level of 8% to about 6%; and (ii) technical losses reduce from the present level of 15% to about 13%.

Total investment in T&D systems in India in India until end of 7th FYP period	= Rs 23,000 crores (1985 prices)
	= Rs 35,000 crores (1990 prices)
Tentative investment level for T&D in 8th FYP period	= Rs 20,000 crores (1990 prices)
Total investment for T&D until end of 8th FYP period	= Rs 55,000 crores

This level of investment gives technical losses of 15%, which we aim to reduce to about 13% by end of the 8th FYP period. Considering an empirical relationship between T&D losses and T&D investment, the additional investment required in T&D systems by end of 8th FYP period is:

$$\left[\left[\frac{15}{13}\right]^{\frac{1}{2}} - 1\right] * 55,000 = \text{Rs } 4,079 \text{ crores}$$
$$= \text{Rs } 40,800 \text{ million (say)}$$

Further reduction of technical losses to 11% by 2000 would involve a further incremental expenditure of the order of Rs. 80,750 million over and above the expenditure to enhance the T&D system to evacuate and distribute 1,00,000 MW of power. The non-technical losses in 2000 are assumed to be 5% - the total T&D loss thereby being 16%.

It may be mentioned that this only gives the upper bound of investment requirement for reduction in technical losses -- as some losses also occur due to improper electrical connections, improper conductor sizing etc.

Incremental expenditure of nearly Rs.120 billion would be required to decrease T&D losses from 23% to 16% between 1990 and 2000. This would result in CO_2 emissions reduction from 94 million tonnes carbon to 85 million tonnes carbon in 2000 if the entire reduction in generation possible due to increased T&D efficiency is assigned to coal-based generation.

Industrial Sector

The industrial sector (manufacturing industry) in India has traditionally been the largest consumer of commercial energy in the Indian economy. In 1988-89, about 34 per cent of the total energy commercial energy available was consumed by this sector. In terms of total final consumption of commercial energy, it was approximately 51 per cent. The contribution of non-commercial energy sources, such as bagasse, rice husk and solar energy, to this sector is negligible. The energy consumption pattern is detailed below in Table 1.2-1.

Table 1.2-1: Energy Consumption Pattern in the Industrial Sector

(Mtoe)

Years	Coal	Oil	Natural Gas	Electricity	Total
1981-82	28.958	8.864	1.003	4.479	43.304
1982-83	32.434	9.292	1.51	4.471	47.707
1983-84	34.017	9.47	1.772	4.819	50.078
1984-85	33.175	10.31	2.142	5.319	50.946
1985-86	36.109	10.413	1.083	5.654	53.259
1986-87	38.49	10.521	3.165	6.035	58.211
1987-88	35.478	11.0	3.859	6.501	56.838
1988-89	39.703	10.876	4.681	7.118	62.378

The consumption of coal, oil, gas and electricity increased steadily throughout the period 1981-82/1988-89, though oil consumption did decrease marginally in the last year. The annual average rate of growth for coal, oil, gas and electricity were 4 per cent, 2.6 per cent, 21.2 per cent and 6 per cent respectively. Total energy consumption increased at a rate of 4.7 per cent on an annual average basis.

It has been estimated that the energy conservation potential that could be realized in the 8th Plan is 15 per cent and 10 per cent in the 9th plan. The Inter-Ministerial Working Group[3] had also estimated the energy conservation potential by type of fuel. It had been calculated that with only the installation of new equipment the savings from coal-based, oil-based and electric machines were in the region of 20 per cent, 20 per cent and 15 per cent. In the short-term, implementation of improved housekeeping measures, training of personnel and energy audits could save about 7.1 MTce, or 2.8 MT carbon emissions on an investment of Rs.4,000 million. The expected savings in monetary terms is

Rs.6,160 million annually. The medium term measures include the installation of waste heat recovery systems, replacement of inefficient boilers, introduction of instrumentation and control systems and adoption of better technology at a cost of Rs.12,000 million. The savings forecast were 8.9 MTCE or Rs.7,720 per annum. This implies annual CO_2 emissions reduction of 3.5 MT carbon. In the long-term introduction of new systems e.g., cogeneration systems, adoption of new energy-efficient technologies and computerization of process control operations are expected to yield a savings of Rs.5,370 million annually i.e., 6.2 MTce. Carbon emissions would reduce by 2.5 MT carbon per year. The investment required for this was estimated at Rs. 20,000 million. The adoption of these measures in the short, medium- and long-term are expected to realize the savings forecast for the 8th and 9th plans respectively.

While there are many reasons for lack of energy efficiency in Indian industry even 11 years after the second oil shock in 1979, there are a few which are important. These are lack of awareness and training, paucity of capital, inadequate incentives, high interest rates, and large customs duty on imported items. Energy conservation policies need to focus on these issues to bring about a change in attitude and a higher level of awareness among industry managers and workers.

Three areas which are vital for a successful energy management programme in any industry are: (i) management (structure); (ii) engineering and (iii) technology. Any programme or policy measure implemented would focus on these areas.

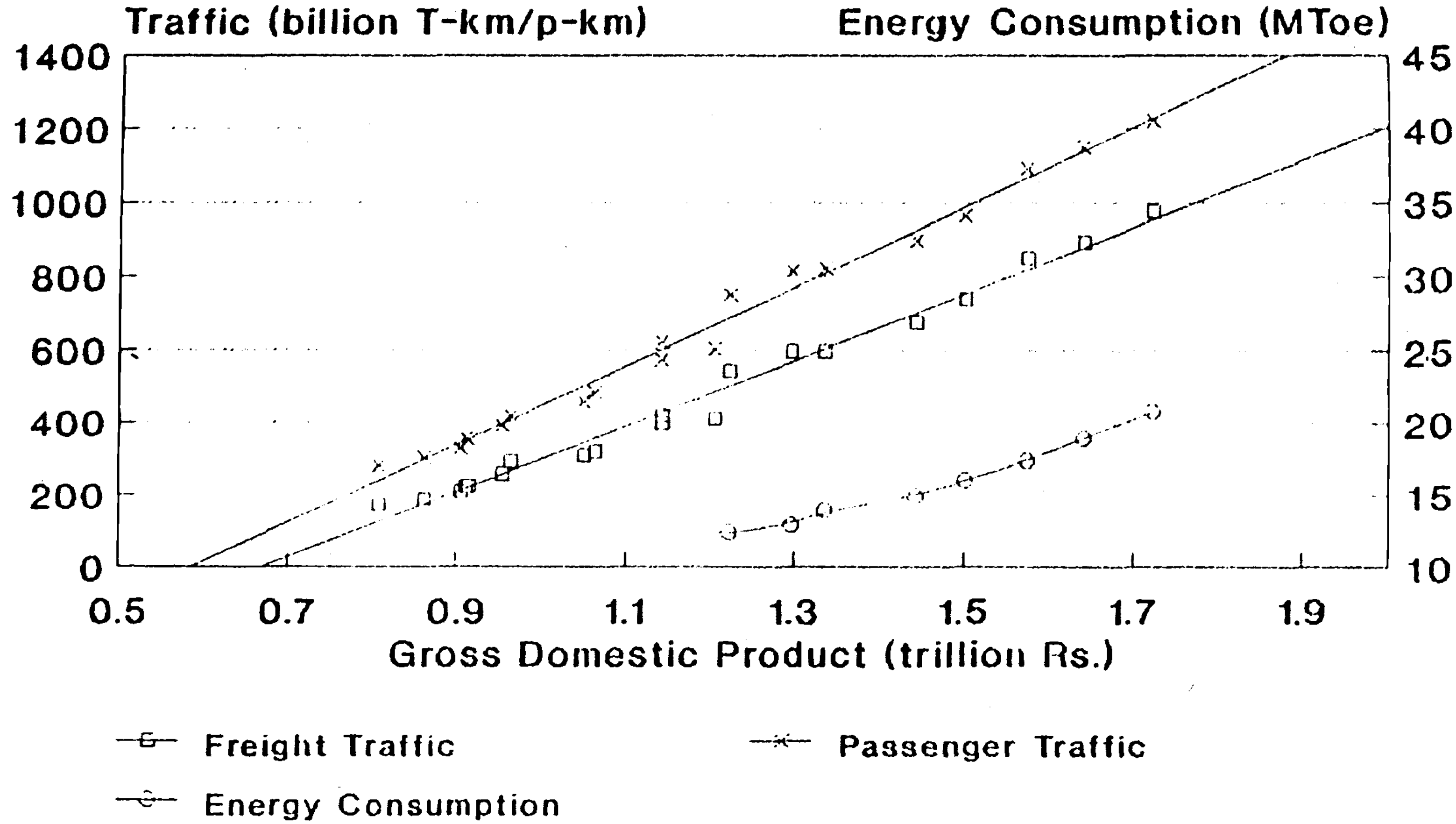
In addition to reducing the fossil fuel consumption drastically in our industry through energy conservation measures, there is a need to bring in solar thermal energy low-grade heat applications on a large scale. We should target for an incremental 5 per cent of total energy use from renewable energy sources (solar; wind and biomass) in each of the next two five-year plans.

Transport Sector

In the years since the Inter Ministerial Working Group report was submitted, the total transport requirement of the country has increased by over 40%[10]. The energy demand of the transport sector over the same period has, however, increased by nearly 70%[4]. Figure 1.3-1 illustrate these trends. The disproportionately higher rate of growth of energy consumption is primarily because of two structural shifts that are occurring in the transport sector. The first is the decreasing share of rail in both freight and passenger movement, and the second is the increased share of personalized modes of transport in passenger traffic: the share of mechanized road transport in passenger traffic increased from 67% in 1970-71 to 78% in 1987-88. In freight traffic too, the share of road transport increased from 34%

[10] Report of the Group on Perspective Planning for the Transport Sector, Planning Commission, Government of India, New Delhi, 1987.

Growth of Traffic and Energy Consumption in the Transport Sector (1969 - 1988)



GDP is at 1980-81 prices

Figure 1.3-1

to 51% over the same period. Neither of these two shifts has been addressed by the Working Group. It is, however, essential to curb these trends if the rate of energy consumption is to be at least equal to, but preferably less than the rate of growth of transport requirement.

Increased rail track kilometerage, higher efficiency and faster movement in the railways and enhanced public transport systems are two necessities for curbing the high rate of energy consumption growth.

Enhanced Public Transport System : A reliable forecast for total urban transport demand is estimated by the "Study Group on Alternative Systems of Urban Transport"[11]. According to this study, under the business-as-usual scenario, the total travel demand for 83 cities of different size and shape with population above 0.25 million is estimated for the year 2001 and is given in Table 1.3-1.

Table 1.3-1: Projections of Urban Travel Demand

Population Range (Million)	Medium Population	No. of Cities	Population (Million)	Travel Demand BPKM per year
8+	13	4	52	314.5
3 - 8	6	3	18	59.8
2 - 4	3	4	12	25.9
1 - 2	1.5	15	22.5	25.6
0.5 - 1	0.75	36	27	15.6
0.25 - 0.5	0.375	21	7.9	1.4
Total		83	124.4	442.8

[11] Report ofthe Study Group on Alternative Systems of Urban Transport, Planning Commission, Government of India, New Delhi, 1987.

Of this total projected traffic demand of 443 BPKM, it is estimated that nearly 20% of the travel demand will be met by sub-urban and urban rail traffic system. While the remaining 80% (i.e. 358 BPKM) passenger travel demand will be met by road transport by the turn of the century.

Road Transport

There has been an exponential growth in motorized vehicles - with an average growth rate of nearly 13% per annum in the last decade. The growth of two-wheelers has been very high (16.6%). The number of cars has also been growing at a higher rate (6.9%) than buses (5.7%) clearly indicating the shift from public transport to personalized transport. And it did not look particularly reassuring : if the present trend of vehicular growth continues, the disparities between supply and demand will become even more acute. To illustrate this fact, we have taken two scenarios : (1) Business-as-usual or as per present trends and (2) One possible scenario and have shown the advantage of replacing personalized transport by public transport not only in terms of energy savings but also in terms of reducing road congestion, pollution and the total cost by the turn of the century. In working out this, the following assumptions have been made:

- Total travel demand by road for the 83 cities is as in Table 1.3-1.
- As per present trends modal split for public transport will be 57% and that of cars 9%[12].

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[12] Urbanization and Energy in the Third World - A Study of India, Tata Energy Research Institute, New Delhi, 1989.

- In the recommended scenario, public transport shares will be 80% and that of cars 4%.
- The balance trips to meet the total travel demand is split in the ratio 2:1 between two-wheelers and three-wheelers in both the scenarios.

Overall, the aim is to reduce work trips by personalized modes of transport (which presently constitute about two-thirds of the total trips by cars and two-wheelers) - by two-thirds. This traffic would be diverted to buses. Further bus capacity is also provided to cater to 50% of the three-wheeler traffic.

The results are summarized in Table 1.3-2.

Table 1.3-2: Implications of Suggested Recommendations

	As per present trends					As per recommendation				
	Bus	Car	2W	3W	Total	Bus	Car	2W	3W	Total
Annual Passenger Kms (10^9)	205	33	80	40	358	288	14	36	20	358
Modal Split (%)	57	9	22	12	100	80	4	10	6	100
No. of vehicles (10^3)	62	1173	7809	532	9576	87	488	3542	260	4377
PCU's (10^3)	186	1173	3904	532	5795	261	488	1771	260	2780
Fuel (10^3 TOE)	1270	1012	1277	733	4292	1786	421	579	359	3145
CO_2 Emissions (10^3 tonnes C)	813	649	818	470	2750	1145	270	370	230	2015
Cost (Rs.crores)	3379	5254	4102	2237	14972	4754	2186	1861	1096	9897

Thus, an increase in bus share from 57% to 80% leads to a saving of 11 lakh tonnes of oil. The other advantages are a 54% reduction in total vehicles on the road, a 27% reduction in carbon dioxide emissions and a 33% reduction reduction in transport costs.

The increase in the number of buses required in the recommended scenario is 25,000 buses. At today's cost this would mean an additional investment of Rs. 10,000 million. If we add 30 per cent for investments in infrastructure, Rs. 13,000 million will be required till the turn of the century to reduce CO_2 emissions by 0.735 million tonnes of carbon.

One disadvantage in the recommended scenario is that about half a million tonne of diesel fuel will be required in addition implying additional imports. This can be got over if two further measures are implemented:

- increasing the traffic carried by electrical suburban rail systems in metropolitan cities by 50 per cent more that projected by the Railways (i.e. 26 BPKM more) giving a saving of 160 thousand tonnes of diesel
- improving fuel efficiency of buses from 3.5 kmpl to 4.5 kmpl leading to a saving of 0.4 million tonnes of diesel. [This could be done partly by technological improvements in bus design and partly by traffic management measures leading to less congestion and faster flow of bus traffic.]

Rail Transport

At present, the only urban rail transport systems in India are in Bombay and Calcutta. Presently plans project that these systems would be providing a capacity of about 80 BPKM by 2000. However, urban rail transport systems lead to a reduction in energy consumption, and hence in CO_2 emissions. It is estimated that such a system in Delhi, costing Rs.25,580 million would provide a capacity of 10 BPKM annually, resulting in net savings of about 0.9 MToe[13]. Consequently, CO_2 emissions decrease by 0.57 MT of carbon.

Providing urban rail transport in Madras and Delhi, and the seven cities in Table 1.3-1 with population between 2 and 8 million so as to move 20% of the traffic (about 40 BPKM) would cost about Rs.1,000 billion, and result in CO_2 emission reduction of about 2.3 MT of carbon.

We, therefore, feel that the modal split suggested by us is feasible. An imaginative policy for bus transportation providing for different types of services, like express, deluxe etc. to cater to different interests would have to be implemented to wean away commuters from personalized transport to buses. What is needed is the will of policy makers to implement such a policy. A change in industrial policy in the automotive sector would also be needed. There will have to be an accelerated production of fuel efficient buses designed specifically for urban transport and a cut back on production of cars and two-wheelers.

Technology for the urban rail system would largely have to be imported: this includes locomotives, signalling and communication equipments, etc.

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[13] Feasibility Report of Metropolitan Railways in Delhi, RITES, New Delhi, 1989.

Increasing the Rail Line Capacity : Increased rail track kilometerage (and accompanying increase in rolling stock) is aimed at ensuring that rail transport provides the same level of service (in terms of speed and reliability) as does road transport. Figure 1.3-2 shows the relationship between freight transport demand and the GDP. The rail freight transport requirement is expected to increase to 0.37 trillion T-km by 2000, and the road tansport requirement to 0.57 trillion T-km under the business-as-usual scenario. With specific energy consumptions of 8 and 21 Toe per million T-km for the rail and road sectors, the annual energy demand for freight transport in 2000 would be about 15 million toe, and CO_2 emissions would be approximately 12 million tonnes of carbon. In order to reduce the energy consumption and CO_2 emissions by one-thirds, an additional 0.38 trillion T-km of rail capacity would have to be provided. The railways plan to create an additional capacity of 0.25 trillion T-km by 2000[14]. Assuming that completely new tracks and rolling stock are required to meet the residual demand of 0.13 trillion T-km, the total incremental investment between now and 2000 is approximately Rs.185 billion based on estimates extrapolated from the Corporate Plan of the Railways[14]. This would result in CO_2 emission reductions of 4 million tonnes of carbon.

This is completely implementable: all infrastructure to develop this additional capacity is available indigenously, or indigenous capability can be enhanced to meet this

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[14] Indian Railways Corporate Plan, 1985-2000, Ministry of Railways, Government of India, New Delhi, 1987.

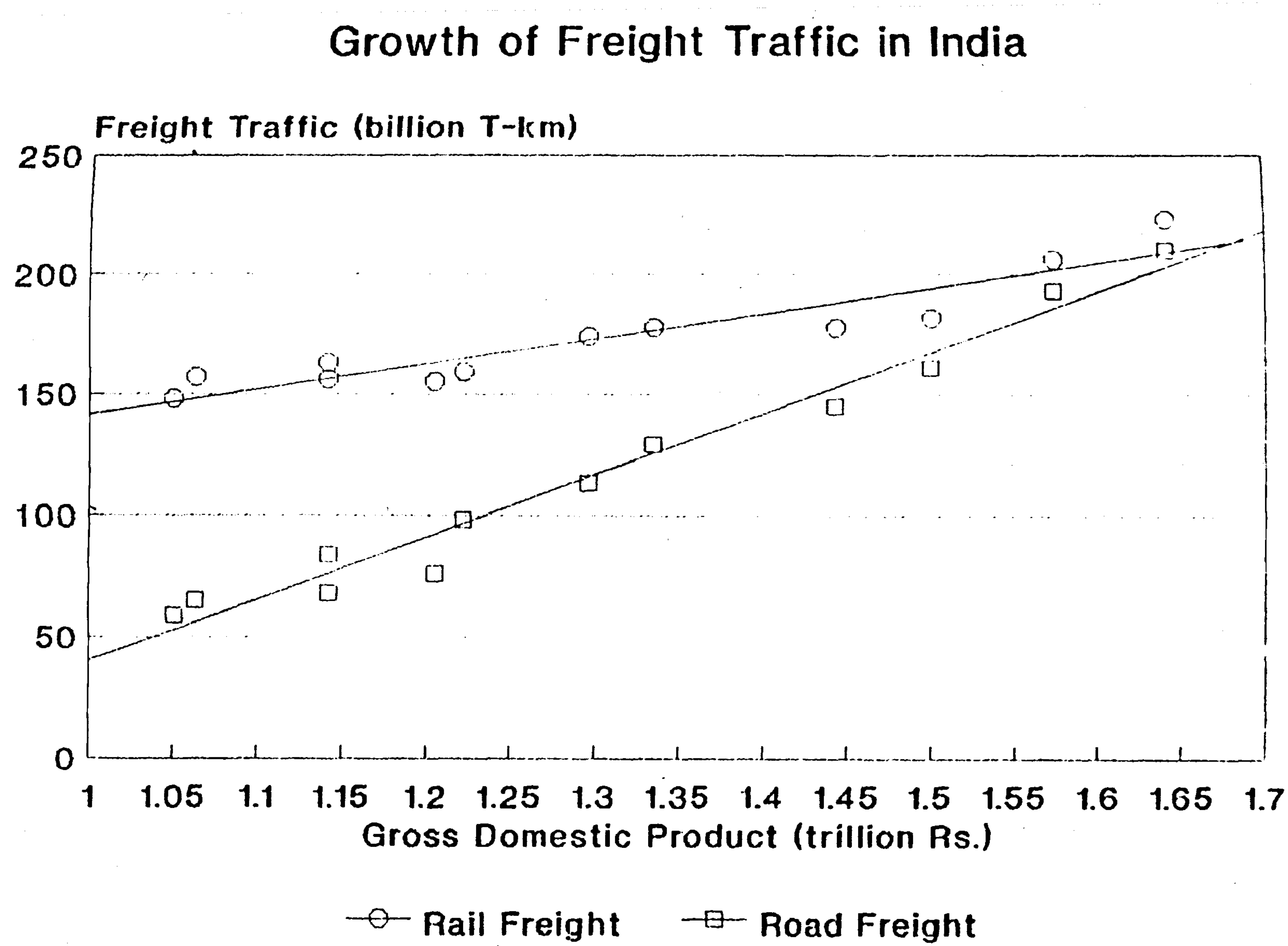

Figure 1.3-2

GDP is at 1980-81 prices

requirement. The only constraint towards the enhancement of line capacity has been, and continues to be, the lack of financial resources.

International funding for meeting the cost of this incremental addition presents a peculiar problem. The projects are economically viable, i.e., an adequate rate of return will be generated, but the income (as well as nearly all the investment) will be in local currency. Given our unfavourable balance of payments position, and the precarious situation of our foreign exchange reserves, it is doubtful whether other sectors of the economy can generate adequate foreign exchange to service this debt. Consequently, total international funding in the form of transfer of resources seems to be the only viable financing mechanism. Finally, since this entire programme would be implemented by the Ministry of Railways, the funding will have to be channeled through the Government of India.

Agricultural Sector

The problems that constrain high energy efficiency in this sector and the energy conservation measures suggested by the Inter Ministerial Working Group[3] largely hold true today as well. The major constraint in the success of these measures is the lack of financial incentives to carry them out. As long as agricultural load tariffs are subsidized, or based only on connected load, there is no incentive to the farmer to instal an energy-efficient motor, or to enhance its energy efficiency. The setting of energy-related tariffs would alone lead to a substantial decrease in electricity consumption - maybe as much as 15% - without any other inputs. On the other hand, without restructuring the tariffs, large inputs could well lead to negligible savings.

There are about 7.6 million electrical pumpsets used in the agricultural sector, which on a nationwide basis, consume approximately 38 TWh electricity every year[4]. It is estimated that complete rectification of these sets would reduce electricity consumption by about 50%[15]. The cost of rectification per set is approximately Rs.8,700 at current prices[15].

The total potential of electrical pumpsets is judged as 12 million[16], and approximately Rs.1.5 million are added in each plan period. It is therefore estimated that there will be about 11 million pumps in 2000. Rectification would cost Rs.95.7 billion, but would result in electricity savings of about 27.5 TWh per year. T&D losses for pumpset supply are 23%; consequently electricity generation of the order of 35 TWh could be avoided. This implies CO_2 emission reduction of 10 MT of carbon.

Domestic Sector

The domestic sector energy conservation potential was not addressed by the Inter-Ministerial Working Group. However, we feel that this is a particularly important sector from the perspective of energy efficiency improvements.

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[15] S.M. Patel, Low Cost and Quick-Yielding Measures for Energy Conservation in Agricultural Pumps, PAJE, 2(1), 3-11, 1988.

[16] V.P.'s Eight Five-Year Plan (1990-95): Status Paper on Power, Planning Department, Government of Uttar Pradesh, Lucknow, 1989.

Biomass Utilization : The most accurate estimates of biomass utilization in the domestic sector are based on 1978-79 NCAER survey[17]. These are summarized in the Table 1.5-1 table along with estimates of future demand.

Table 1.5-1: Demand for Traditional Biofuels in 2004/05 (million tonnes)

Source	Population (million)	Fuelwood	Dungcake	Agricultural Waste
NCAER+,[17]	641	95.5 (79.3)	71.7 (66.7)	30.6 (29.5)
WGEP[18]	-	61.3	33.6	18.9
ABE[2]	1046	312.0	207.0	94.0
EDSG[19]	1040	258.9 (187.0)	150.5 (132.2)	77.0 (71.8)
TEESE*,[20]		63.4	82.2	42.9
NCAo,[21]	-	150	-	-

Note: The numbers in brackets indicate estimates of rural energy demand.

+ These were consumption levels in 1978-79.
* The estimates are for the year 2005.
o The estimates are for the year 2000.

[17] I. Natarajan, Domestic Fuel Survey with Special Reference to Kerosene, Vols. 1 and 2, National Council of Applied Economic Research, New Delhi, 1985.

[18] Report of Working Group on Energy Policy, Planning Commission, Government of India, New Delhi, 1979.

[19] Report of Energy Demand Steering Group, Planning Commission, Government of India, 1986.

[20] Development of a Quantitative Model for Systems Evaluation of Energy Related Technologies (TEESE Model), Tata Energy Research Institute, New Delhi, 1988.

[21] Central Forestry Commission, India's Forests, Forest Research Institute and Colleges, Dehradun, 1985.

Assumptions Made in Various Studies

WGEP[18]

a) Total household energy consumption norm is fixed at 0.4 tcr per capita per annum in urban areas 0.38 tcr per capita per annum in rural areas

b) The use of commercial energy sources will increase to such an extent that the consumption of the non-commercial fuel for cooking will be reduced to about 70 per cent of households in the rural areas and 10.8 per cent households in urban areas in the year 2000.

c) The allocation of non-commercial fuels among fuelwood, agricultural residues and dungcake is assumed in the ratio of 65:20:15.

ABE[2]

a) Total household energy consumption norm is fixed at 650 kcal per capita per day.

b) NCAER 1978/79 pattern of fuel consumption will be valid for 2004/05 also.

EDSG[19]

a) The average useful heat consumption
= 650 kcal per capita per day for urban population
= 520 kcal per capita per day for rural population

b) Stove efficiency is 8 per cent.

c) NCAER pattern of fuel consumption will be valid for 2004/05.

TEESE

a) Fuelwood demand is fixed at the level of its consumption estimated for 1984-85.

b) Dungcakes availability is determined within the model as a function of the optimal number of draught cattle and a fixed number of milch cattle.

In the context of strategies for limiting CO_2 emissions from India, strategies to reduce demand for woody biomass play an important role. In this context the role of the programmes to promote biomass stoves becomes significant.

The current National Programme on Improved Chulhas (NPIC) has a target of 1.827 million stoves for 1990-91 at a financial outlay of Rs.125 million. It is estimated that by the end of the year 1989-90, there will be about 8 million improved cooking stoves on the ground. It is estimated that approximately 65% of installed improved chulhas are used, and that these result in a 25% reduction in wood consumed; about 0.23 tonnes wood annually[22] for each chulha. An outlay of Rs.125 million, therefore results in the saving of 0.270 MT of wood annually, or a reduction in CO_2 emissions of 0.12 MT of carbon.

Considering that there are about 80 million traditional biomass stoves in the country, and that annual targets are of the order of 2 million chulhas, about 30 million chulhas would be in place by 2000. Additional resources of the order of Rs.2000 million would place another 30 million chulhas in place, and reduce CO_2 emissions by 2 MT of carbon every year.

[22] V Joshi, Rural Energy Demand and Role of Improved Chulha, in <u>Energy Policy Issues</u>, Volume 4(1988), Tata Energy Research Institute, New Delhi, 1989.

It is obvious that this strategy alone is not adequate to limit and improve the role of biomass fuels in cooking.

A more comprehensive enduse based planning approach using following strategies in the domestic sector may contribute to varying degree towards limiting CO_2 towards emissions from India.

1) More rapid and effective promotion of biomass based improved cooking stoves and biogas plants.
2) In the long term biofuels should be processed to obtain better quality fuels to be used with higher efficiency.
3) Implementation of area based cooking energy plans to substitute biomass with better quality fuels. For example,
   - o Excess hydro-power in the hills,
   - o Piped NG near the north-east and other NG rich areas,
   - o Coal briquettes or coal gas mixture in the coal belt,
   - o Sewage gas in urban areas.

Lighting : The current stock of electric lamps in India is about 600 million: 400 million incandescents and 200 fluorescents. Incandescent lamps convert about 4% of the input electricity into light, whereas the conversion in fluorescents is about 10%. Compact fluorescents are currently not manufactured in India, and cost about Rs.250. Their life is in excess of 8 years; tube fluorescents have a rating of 50 W, last 4 years, and cost Rs.125; incandescents cost about Rs.50 to install, last about an year, and have an average rating of about 80W.

It is projected, current trends continuing, that the installed lamp stock in India would be about a billion in 2000: 600 million incandescents and 400 million fluorescents. Approximately 50% of the 80W incandescents are judged to be replaceable by 50W fluorescents. The incremental cost of this conversion would be about Rs.22.5 billion, but the annual energy savings would be 9 TWh. Assuming T&D losses of 23%, and coal-based generation to account for 70% of total generation, the reduction in energy requirement would be about 8.2 TWh annually. This implies CO_2 emission reduction of 2.5 million tonnes of carbon.

Alternately, if all tube fluorescents and 50% incandescents are replaced by compact fluorescents, the cost would be Rs.110 billion, but energy savings would be 43 TWh, or 39 TWh of coal-based electricity. This implies CO_2 reduction of 13 MT of carbon.

Deployment of Renewable Energy Technologies

In the future, with the growth in the demand for energy, judicious resource use will have to be the cornerstone of a sustainable development effort, in which renewable energy sources can, and will, play an important role. Even at the present costs there are many applications in which some renewable energy technologies are cost effective in addition to being environmentally benign.

In the power sector, for example, windfarm power generation competes favorably with the cost of coal thermal route to electrical power generation. In the past five years, the Department of Non-conventional Energy Sources (DNES) has commissioned a total of 10.1 MW of windturbines which have fed over 22 million kWh of electricity to the central grid at costs averaging in the range of Rs. 1 to Rs. 1.5 per kWh. The estimated costs in the future are expected to be as low as Rs. 0.80 per kWh and the DNES proposes to add as much as 5,000 MW of wind-power generating capacity by 2000 A.D. A study by the Tata Energy Research Institute[23] estimates the potential of windfarms in India at about 16,000 MW while DNES places this figure at 20,000 MW. In reality the ultimate potential for harnessing wind for power generation is much higher (according to the TERI study, the ultimate potential exceeds 200,000 MW and is limited by the maximum possible penetration in the existing grid) and would depend on the development of low cost energy storage systems in order to increase the penetration.

There is, similarly, a large potential for solar energy applications. Though soalr energy applications are likely to be more cost effective in the medium temperature (100-150°C) range, there are a whole range of applications which are and are likely to be cost effective in the comming decade. These can have a significant effect on the reduction of fossil fuel consumption.

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[23] J Hossain, An Assessment of Potential for Installation of Windfarms in India, Paper presented at the PACER Conference on Role of Innovative Technologies and Approaches for India's Power Sector, Organized by TERI and PFC, Delhi, April 1990.

For example, the savings from the targeted low and medium temperature solar thermal devices recommended for the Eighth Plan period (DNES, 1988) based on the possible displacement of alternate fuels is given in Table 2-1 below. The proposed 0.46 million family solar cookers would displace an estimated 276,000 tonnes of fuelwood per year while the community solar cookers could substitute about 50,000 tonnes of fuelwood annually if deployed solely in rural areas or reduce consumption of fossil fuel based energy sources in urban areas. The benefits/savings from domestic hot water systems, based on the quantity of electricity displaced, is estimated at 41.7 MkWh per year, while for industrial hot water systems and solar air heaters the estimate is based on fuel oil savings. The estimated savings total about Rs.4800 million annually while the one time investment amounts to Rs.2,125 million. It should be noted that the savings accrued from the solar technologies (especially for industrial applications) are through the savings in commercial, and largely fossil, fuels and thus there are possibilities of considerable reduction of consumption in these sectors.

Table 2-1: Savings from Solar Thermal Devices

	Number	Cost (Million, Rs.)	Savings (Million-Tonnes Carbon)
1. Solar - low and medium temperature			
(a) Solar cooker			
(i) family size	460000	296.6	0.12
(ii) community	21500	67.6	0.2
(iii) concentrating models	500	3.0	0.02
(b) Hot water systems			
(i) Domestic	46000	341.4	0.01
(ii) Industrial	460000 sq.	1220.0	0.07
(c) Solar timber kiln	0.11 m.cu. (775 in #)	109.0	0.01
(d) Solar air heaters/dryers	50000 sq.m (100 in #)	88.0	0.02
TOTAL		2125.6	0.45

In Table 2-2, the proposed plans of the Sub-group on Solar Thermal Technologies (for the Eighth Plan) for power generation through the use of solar energy is summarized. Though there are no operational line focusing, steam cycle power plants in the MW range, the Sub-group felt that the target of 8 plants of 30 MW installed capacity each was achievable in the Eighth Plan period. The estimated costs of the recommended projects are listed below in Table 2-2. The annual CO_2 emissions from coal-based TPS generating equivalent energy are also listed in Table 2-2.

Table 2-2: Solar Thermal Power Generation Proposal: Summary

Solar- high temperature	Number/ apacity	Total cost (million, Rs.)	Cost/KW (Rs./KW)	CO_2 Emission Reduction (MT of Carbon)
(a) Line focusing-steam cycle power plant	8 (8x30MW)	2987	41458	0.18
(b) Dish-Stirling power plant	11 (148KW)	20.8	269595	Negligible
(c) Solar pond power plant	2 (650KW)	28.0	43077	Negligible
TOTAL		303.58		

Based on the potential for other renewable energy sources, our estimates of DNES projections for the achievable targets are listed in Table 2-3 below, alongwith CO_2 emissions from coal-based TPS generating equivalent electricity.

Table 2-3: Proposed Plans for Renewable Energy Utilisation in India by 2001 AD

	Proposed Installed Capacity (in MW)	Budgetary Requirement (in Million Rs.)	Reduction in CO_2 Emissions (Million Tonnes Carbon)
Power from Biomass	6000	8000	7.79
Power from Wind	5000	7500	3.68
Power from Small Hydro	2000	4000	1.96
Energy from Sewage Sludge	50	125	0.08
Energy from Distillery	140	49	0.22
Energy from Municipal Solid Waste	160	533	0.25
Photovoltaic pumps	15	156	0.01
Windpumps	50	91	0.05

Source: Energy 2001: Perspective Plan (for) Non-conventional Energy Sources, Department of Non-conventional Energy Sources (DNES), Govt. of India, 1987.

The estimated budgetary requirements for the proposed programmes are listed in the same table (the biogas and cookstove performance, which account for nearly 70 percent of the expenditure by DNES, are <u>not</u> included in the table). Going by the financial constraints and the current trends in financial allocation, it seems unlikely that the requisite funding for the proposals will be forthcomming. As pointed out, part of this has to do with the supply oriented approach to energy planning in India which places emphasis on addition to energy production capacity.

A more rational approach to planning for energy sector requires the consideration the service provided by energy rather than energy per se. Often referred to as 'end use' planning, this method permits an analysis of the different energy conversion routes to meet energy end uses, permits the utilization of higher efficiency (both, the First and the Second Law) energy conversion paths of satisfying these end uses, allows a possible change to thermodynamically suitable fuel mix for different end uses, and can lead to energy policies which can result in a significant delinking of growth of energy consumption from development and is more likely to promote a sustainable development effort. The end use approach, in conjunction with the actual cost of delivered energy, also leads to a realistic assessment of the cost effectiveness of different source-technology-end use combinations from the viewpoint of the society. When this procedure is followed, it can be shown that even the 'expensive' photovoltaic technology is cheaper than providing the same energy service by extending the grid at many places in India. The cost-effectiveness of other commercially available renewable energy technologies for irrigation such as windmills, gasifier and biogas based dual fuel engines, biomass based Stirling engines are better and less ambiguous. The same is true for many other energy end uses such as rural lighting, motive power for many small-scale industrial requirements, medium and low temperature thermal energy requirements in both, the domestic and the industrial sector, energy for refrigeration in health care, telecommunication in remote areas, and so on. The potential of renewable energy sources and related technologies, therefore, is immense.

Availability of technology for meeting these diverse end uses is not the main problem. In India today the list of available innovative technologies based on renewable energy sources is impressive. Some of these have been discussed and many others can be listed. The major problem lies with the low priority attached to the renewable energy sector and the lack of funds earmarked for the utilization of these energy resources. For example, in the Seventh Plan period while the power sector received over Rs.3,42,700 million, the total allocation to the renewable energy sector was a meager Rs.5,200 million.

It would, however, be misleading to give the impression that all the renewable energy technologies have achieved the level of maturity or sophistication that is associated with the conventional routes to energy conversion. Here also, part of the reason can be attributed to the lack of funding to the renewable energy technologies. Therefore, the question of resource mobilisation for development of non-conventional forms of energy is critical to the whole programme in this area.

Afforestation

The Government of India has been striving to meet the stated objective of afforesting 30% of India's land area - about 328.8 million hectares (Mha). The annual planned afforestation is of the order of 5 Mha, but less than 2 Mha per year has been achieved[24] due to number of reasons, principally the lack of financial resources.

The total area under forest cover decreased from 64.2 Mha in 1985 to 64.0 Mha in 1987 as indicated by satellite imagery (reconciled with ground data) with a minimum resolution of 25 ha[25]. Consequently, deforestation, as measured by satellite imagery, is of the order of 0.1 Mha per year.

It should be noted that estimates of the rates of deforestation vary from 0.1 million hectares to 1.2 million

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[24] India's Forests - 1987, Department of Environment, Wildlife & Forests, Government of India, 1987.

[25] State of India's Forests, 1989, Forest Survey of India, Dehradun, 1989.

hectares each year. The biggest reason for deforestation is grazing, lopping and firewood collection. The demand of firewood is assessed to be around 225 million tonnes. The recorded production is only about 100 million tonnes. Thus, there is a gap of about 125 million tonnes. This is currently met primarily from the liquidation fellings. Added to this problem, the grazing pressure of around 467 million heads of livestock need about 1058 million tonnes of fodder. Most of this is collected free. At the same time, afforestation through social forestry programs has been of the order or 2 Mha per year. Most of these plantations are either in small woodlots which are less than 25 ha in area, or in strip plantations along canals, roads and railway lines. Neither of these plantations are visible through satellite imagery, and therefore could not have figured in the forest area computations. It should be pointed out that 2 Mha is not the actual area under afforestation but is notional. The area has been worked out on the basis of 2,000 plants per hectare. The actual planted area is less than 50% of the achievement shown as the planting stocking varies from 2,000 to 10,000 seedlings per hectares. Most of the land where afforestation work has been done continues to be under grazing and other uses. The actual success of plantation is very much below the targets shown to be achieved. Assuming a 50% survival rate in social forestry plantations, the net change of area under forest cover works out to between 0.2 Mha net deforestation and 0.5 Mha of net afforestation. Consequently, the situation is precarious - and distorted towards deforestation, and only massive afforestation can result in a net decrease in carbon dioxide emissions.

If the stated objective of foresting one-third of India's land area is to be achieved by 2000, 15 Mha of afforestation are required over the next 10 years. The planned afforestation is expected to be about 3 Mha per year over the next 10 years. Assuming 50% survival, the net afforestation is 15 Mha over the decade, while required afforestation is 150.

The incremental afforestation is, therefore, 270 Mha over the next 10 years. This would cost Rs.810 million. At an average wood stock of 25 tonnes per hectare, the incremental CO_2 sequestered over ten years would be about 3750 million tonnes of carbon, or 375 million tonnes of carbon per year.

If afforestation is required to be done for CO_2 assimilation, the tree cover once created must be maintained. Unfortunately in the present planting programmes there is an undue emphasis on meeting the demand of fodder and fuel. The plantations created under the previous five-year plans have mostly been used up and they do not, therefore, contribute to CO_2 assimilation. If plantations are desired to be carried out for CO_2 assimilation then the afforestation must be followed with a good system of management so that the vegetal cover once created stays on the ground. Fortunately, trees keep on increasing in the crown size. Consequently, the CO_2 assimilation per tree increases with age upto maturity of tree. A system can, therefore, be devised that afforestation can be used simultaneously for wood production as well as Co_2 assimiliation. This, however, will need a very good system of forest management. Mere afforestation and using up of the biomass so produced is not going to help the cause of Co_2 assimilation.

APPENDIX I

IDENTIFICATION AND QUANTIFICATION OF ENERGY CONSERVATION MEASURES BY THE INTER MINISTERIAL WORKING GROUP, 1983

A. INDUSTRY SECTOR

Sl. No.	Recommendation	Saving Expected: In Million Tonnes of Coal Equivalent Per Annum	Saving Expected: In Rs., Crores Per Annum	Investment (in Rs., Crores)	Remarks
	Short Term Measures				
i.	Implementation of good keeping measures	7.1	616	400	House keeping measures include tuning of combustion equipments, proper maintenance of energy consuming equipments, condensate recovery insulation, etc.
ii.	Training of industrial personnel in energy				
iii.	Introduction of system of energy audit.				
	Medium Term Measures				
iv.	Installation of waste heat recovery systems	8.9	772	1200	Investment figures indicated have to be borne by industry and government, the major portion being met by the industry
v.	Replacement of old inefficient boilers by high efficiency boilers				
vi.	Introduction of instrumentation and control systems				
vii.	Adoption of better technological innovatives like ceramic fibers low excess air burners variable speed drives, etc.				
	Long Term Measures				
viii.	Introduction of Co-generation systems	6.2	537	2000	
ix.	Adoption of newer energy efficient technologies.				
x.	Introducing computers for process control on real time basis				
	Total	22.2	1925	3600	

B. TRANSPORT SECTOR

Sl. No.	Recommendation	Saving Expected: In Million Tonnes of Coal Equivalent Per Annum	Saving Expected: In Rs., Crores Per Annum	Investment (in Rs., Crores)	Remarks
Short Term Measures					
i.	Accelerating the national programme on education campaign for users of road transport	1.68	240	200	
ii.	Enforcing speed limits and abolishing octroi checkposts	0.73	105	30	
iii.	Emulating the concept of model depots in State Transport Undertaking	0.21	30	60	
Medium Term Measures					
iv.	Adoption of energy efficient technology for new heavy vehicles, automobiles and 2/3 wheelers	a) 1.05 b) 0.31	150 90	300 200	a) For heavy vehicles b) For automobiles and 2/3 wheelers
v.	Formulating and implementing a plan for upgrading the quality of road surfaces	1.05	150	100	The investment has to be incurred on a recurring basis every year
	Total		765	890	

C. AGRICULTURAL PUMPSETS

Sl. No.	Recommendation	Saving Expected: In Million Tonnes of Coal Equivalent Per Annum	Saving Expected: In Rs., Crores Per Annum	Investment (in Rs., Crores)	Remarks
Short Term Measures					
i.	Initiating of national education and awareness programme on energy conservation in lift irrigation pumpsets			100	
ii.	Organizing programme for remedying the installation defects in the existing pumpsets	1.6	340	400	Installation defects like undersizing of suction and delivery pipes, high resistance foot valves, etc.
Medium Term Measures					
iii.	Technology development for high efficiency pumpsets and oil engines and introducing the same for new pumpsets	0.33	70	150	
	Total	1.93	410	650	

TECHNOLOGICAL OPTIONS FOR REDUCING GHG EMISSIONS FROM COAL-BASED POWER GENERATION

Dr. Ajay Mathur

Introduction

The installed electricity generation capacity in utilities in India at the end of 1989-90 was 62,354 MW, and the total generation during the year was about 233 TWh; coal-based thermal power stations (TPSs) accounted for about 65% of the total installed capacity and 70% of energy generation. During the past two decades, the role of coal-based generation in the country's electricity-mix has been steadily increasing because of a number of reasons, principally their shorter gestation periods and lower capital requirements, especially as compared to those of hydroelectric projects. In addition, the annual specific generation of hydroelectric power stations has been decreasing, while that of coal-based TPS has been rising. These trends are illustrated in Tables 1 and 2. Table 1 shows the changes in the production mix of electricity over the past two decades, as well as some performance indicators such as annual specific generation and auxiliary consumption, and gross efficiency of TPSs. Table 2 shows the time and cost overruns in recent hydro, thermal and nuclear projects.

Table 1: Performance of the Indian Power Sector

	Installed Capacity			Gross Generation			Annual Specific Generation (kWh/kW-year)		Auxiliary Consumption (% of Gross Generation)			Gross Efficiency of TPS
	Hydro (%)	Thermal (%)	Total (MW)	Hydro (%)	Thermal (%)	Total (MW)	Hydro	Thermal	Hydro	Thermal	Total	
1970-71	43.4	53.7	14709	45.3	50.5	55.8	3956	3562				
1975-76	42.1	54.7	20117	42.1	54.7	79.2	3935	3932.				
1980-81	39	58.1	30214	42	55.3	110.8	3947	3940				
1982-83	36.9	60.6	35363	37.1	61.3	130.3	3705	3724				
1986-87	32.9	64.4	49266	28.7	68.7	187.7	3324	4060	1	10.49	7.63	28.8
1989-90	31.8	65.4	62354	27.2	70.3	233	3187	4006				

Source: EA (1990) and TERI (1990)

Table 2: Time and Cost Overruns of Some Electricity Projects

Project	Capacity (MW)	Cost			Time		
		Original	Actual	% Overrun	Original	Actual	% Overrun
		(Crores Rs.)			(Months)		
Hydroelectric Projects							
Beas-Sutluj Link							
Dehar	4X165	97.67	382.57	291.7	120/144	192	60.0/33.3
Pong	4x60	75.34	259.80	244.8	120	192	60.0
Kalinadhi I	6x135	125.66	228.23	81.6	72	102	41.7
Idukki	3x130	68.20	115.00	68.6	60	108	80.0
Loktak	3x35	10.10	80.62	698.2	72	144	100.0
Baira Suil	3x60	20.49	92.20	35.0	60	120	100.0
Kyredumkulai	2x30	9.24	23.28	15.2	48	96	100.0
Lower Jhelum	3x35	17.98	72.53	30.34	84	108	28.6
Subernakha	1x65	15.26	31.80	108.4	60/72	84	40.0/16.7
Giri	2x30	8.71	26.76	207.2	60	132	120.00
Gumti	2x5	3.09	16.60	437.2	60	120	100.0
Salal		55.15	222.15	302.8	96	192	100.0
Srisailam		45.75	237.26	418.6	84	192	128.6
Balimala		45.82	89.94	96.3	72	96	33.3
Thermal Projects							
Santaldih	4x120	75.58	106.89	41.4	110	111	0.9
					122	129	5.7
					149	182	22.1
					158	188	18.9
Patratu	2x110	35.16	63.49	80.6	9/111	124/138	25.3/24.3
Panki	2x110	35.20	70.0	98.9	71/76	78/72	9.9/-5.3
Obra	5x200	157.9	374.4	137.1	33	51	54.5
					39	63	61.5
					51	81	58.8
					57	90	57.9
					60	90	50.0
Kothagundam	2x110	42.3	79.12	87.0	58/61	61/71	5.2/16.4
Amarkantak	2x120	41.37	75.35	82.1	53/62	59/68	11.3/8.8
Chandrapma	1x120	19.95	39.50	98.0	61	79	29.5
Gandhinagar	2x120	45.60	58.25	27.7	50/53	53/53	1.5/0
Badarpur	1x120	38.37	66.4	73.1	55	67	2.18
Vijaywada	2x120	76.86	156.64	103.8	66/72	77/82	16.7/12.5
Koradi	1x200	112.4	212.50	89.1	42	61	45.2
	2x210				54/66	94/101	74.1/53.0
Panipat	2x110	46.57	86.0	84.7	53/59	71/77	71.7/64.4
Tuticorin	2x210	75.05	152.30	102.9	61/67	68/76	11.5/13.4
Satpura	2x200	75.19	136.0	80.9	55/62	67/64	21.8/3.2
Bhatinda	2x110	41.38	71.15	71.9	54/60	51/61	-5.5/1.7
Ukai	2x200	78.30	88.31	12.8	38/50	53/62	39.5/24.0
Nuclear Projects							
RAPS-1	220	33.95	73.27	115.8	96	96	0
RAPS-2	220	58.16	95.90	64.9	117	156	33.3
MAPS-1	235	61.78	107.87	74.6	132	156	18.2
MAPS-2	235	70.63	103.02	46.1	132	187	41.7

Source: : Report of the Committee on Power, Ministry of Energy, 1980.

Apart from the technical, financial and managerial parameters indicated in Tables 1 and 2, both hydro and nuclear plants are also facing increased public resistance on account of their perceived impacts and risks, such as the displacement of populations, the possibility of accidents, and ecological impacts associated with large-scale submergence and with the nuclear fuel cycle. These have lead, especially in recent years, to public opposition which has decreased the reliability of the commissioning of these projects on the time schedule and budget originally envisaged by project authorities.

All these factors have together lead to a situation where decision makers prefer to invest in coal-based generation capacity. They cite the proven technology, the comparatively short gestation periods (often as short as forty eight months for a 210 MW unit and then six months for each additional unit of that capacity), and the large indigenous reserves of non-coking coal for their preference. This is not to imply that coal-based electricity generation is without environmental hazards; the impacts have, however, been traditionally viewed as being limited in their area of influence and in the risk potential they present to populations. Most pollutants emitted from TPSs are also amenable to end-of-pipe control technologies which do not require changes in the electricity generation technology itself, and are, therefore, managerially attractive. Paradoxically, the greatest impact from TPSs seems to be from two substances that have low toxicity - ash and carbon dioxide. Both these effluents are discharged in such large quantities that they affect and alter the "sink" in which they are disposed.

Future plans for electricity supply continue to rely heavily on coal-based power generation. The Energy Demand Screening Group (Planning Commission, 1986) projects electricity generation requirement of nearly 783 TWh in 2004-05, and expects coal-based generation to provide about 60% of this requirement (based on a supply of 329 million tonnes of non-coking coal to utilities, and a specific coal consumption of 0.7 kg coal/kWh). The Group projects total auxiliary consumption to be 7%, i.e., approximately the same as the present level as indicated in Table 1. Consequently, if auxiliary consumption in coal-based TPS is also assumed to remain at the present level (10% of gross generation), the net electricity production (at busbar) in 2004-05 from 329 million tonnes of non-coking coal would be 423 TWh. With an approximate carbon content of 40%, the specific carbon dioxide emission is expected to be 1.14 kg of CO_2 per kWh electricity delivered at busbar.

The other major specie of greenhouse gas emitted during coal-based electricity generation are oxides of nitrogen (NO_x). The major factors controlling their production are combustor temperature and amount of excess air used: higher temperatures as well as more excess air favour NO_x formation. Consequently, emission rates are largely dependent on the technology employed for coal combustion. Presently, all utility coal-based TPS employ pulverized-coal boilers for steam raising. The formation of NO_x in these boilers is of the order of 5 to 7 grams of NO_x per kWh generated (0.8 to 1.2 grams of NO_x/m^3 of flue gas), or 5.5 to 7.7 grams of NO_x per kWh delivered at busbar. The global warming potential of NO_x is 290 times that of CO_2 (IPCC, 1990); NO_x emissions are, therefore, equivalent to an additional 1.6 to 2.2 kgs of CO_2 per kWh delivered. At this stage, a more precise distribution of specific NO_x emissions from coal-based TPS in India is not available. Consequently, an arithmetic average of 6.6 grams of NO_x per kWh delivered is assumed to be a representative value. The corresponding equivalent CO_2 level of NO_x production is 1.91 kgs of CO_2 per kWh generated.

In the following analyses, various technological options are assessed that would lead to a reduction in the specific CO_2 and NO_x emissions from coal-based power generation in India. The specific emissions of 1.14 kg CO_2 and 6.6 grams of NO_x per kWh delivered, and a total requirement of 423 TWh of coal-based electricity in 2004-05 are employed as benchmarks in assessing the potential CO_2 emission reduction for each option.

Reduction of specific emissions of CO_2 and NO_x during coal-based electricity generation is dependent on increasing power plant efficiency. In the short term, we look at technological options that can increase the efficiency of TPS based on pulverized coal boiler technology, as well as at NO_x control technologies. In the medium and long term, other options based on advanced coal conversion technologies for power generation can be assessed in the perspective of their suitability for use with Indian coals, cost of electricity generation, and environmental impacts.

Efficiency Enhancement Options for Pulverized Coal TPS

Pulverized coal combustion technology, depicted schematically in Figure 1, involves the crushing and grinding of coal to very fine dust (approximately 75 microns in diameter) and blowing this dust, alongwith air, into the boiler. The "coal breeze" burns as it moves through the boiler, generating heat. This heat is absorbed by water flowing through tubes lining the boiler walls; the water is converted into high pressure steam and drives a turbine to produce electricity. The low pressure steam from the turbine is cooled to water in a condenser and the water is recycled to the boiler.

During combustion in the boiler, coal ash and other combustion products (CO_2, NO_x, sulphur dioxide, etc.) are produced. The gaseous products, as well as part of the ash are carried up a flue and discharged into the atmosphere. Most cleanup (for removing ash, sulphur dioxide, NO_x, etc.) is carried out between the boiler exit and the flue. The ash that is not carried away by the flue gas falls to the bottom and is removed (alongwith fly ash collected from the flue gases) by slurrying it with water.

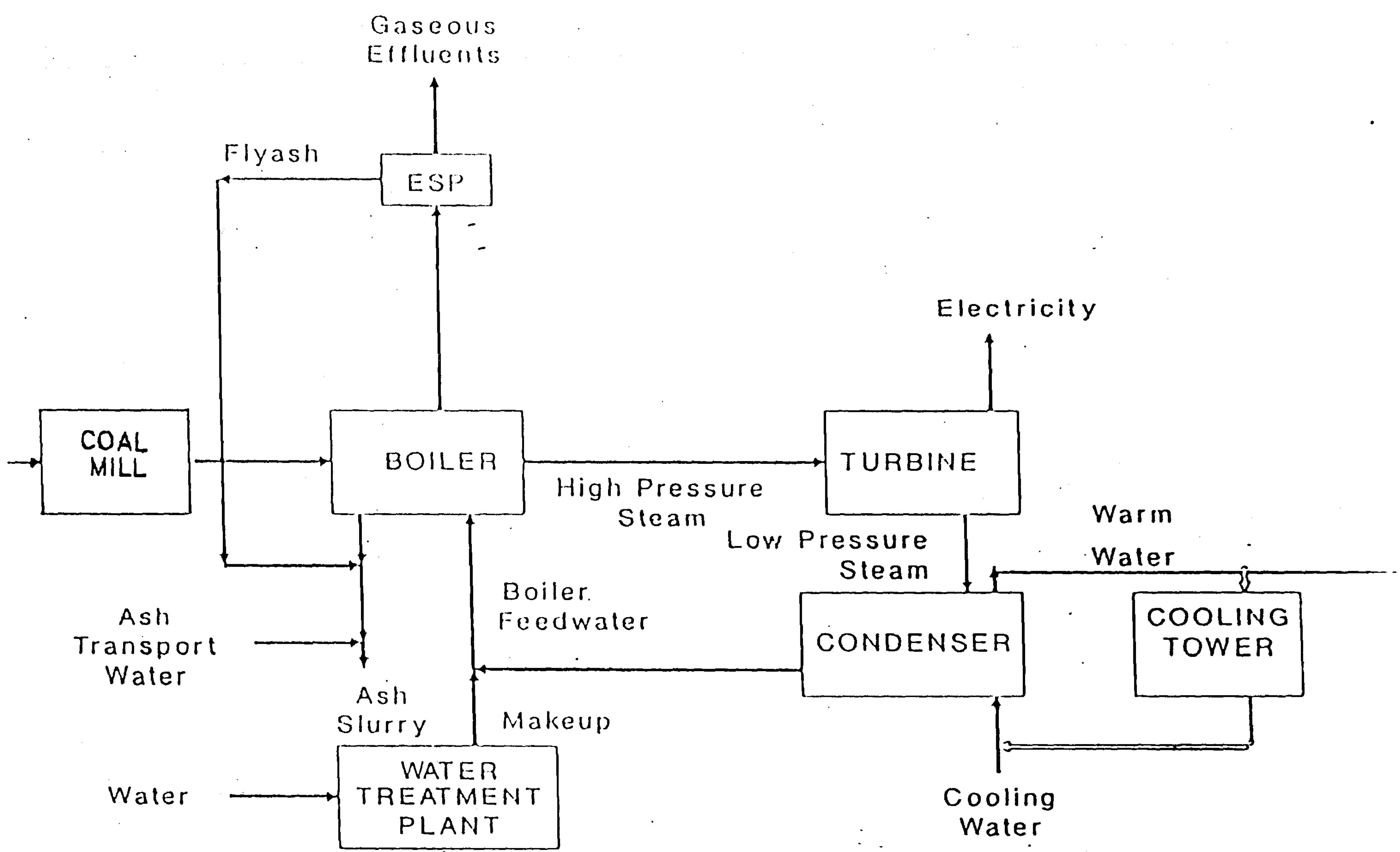

Fig. 1: Schematic Diagram of a Pulverized Coal Boiler - Steam Turbine Power Station

Some of the electricity generated is used to power TPS equipment such as coal handling plant, coal crushers and mills, pumps, etc. Apart from this, there are some electrical loses associated with transformers, capacitors, etc. All these are together termed as auxiliary consumption; and net generation (or electricity delivered at busbar) accounts for these losses and inplant consumption. Figure 2 shows "typical" energy flow paths in a pulverized coal TPS. The numbers in Figure 2 are based on design norms currently in India, and indicate an overall coal-to-electricity conversion efficiency of 31.6%.

The operating efficiency of coal-based TPS in India is, however, much lower. The efficiencies of individual stations varies from less than 10% to as high as 33%. Figure 3 shows the distribution of station efficiencies with respect to installed capacity in 1986-87 (CEA, 1990); the capacity weighted efficiency is 27.8%. About 30% of the installed capacity operates at efficiencies above 30%, but about an equal proportion (25%) operates at efficiencies below 25% as well. Station efficiencies are not the best indicators of performance inasmuch as each station has a combination of units of varying capacities and vintages. Units that are small and old, and consequently inefficient, tend to reduce station efficiency. However, the generation from these units is comparatively small and hence, generation weighted station efficiency could be considered a more appropriate performance indicator. This was 28.8% in 1986-87.

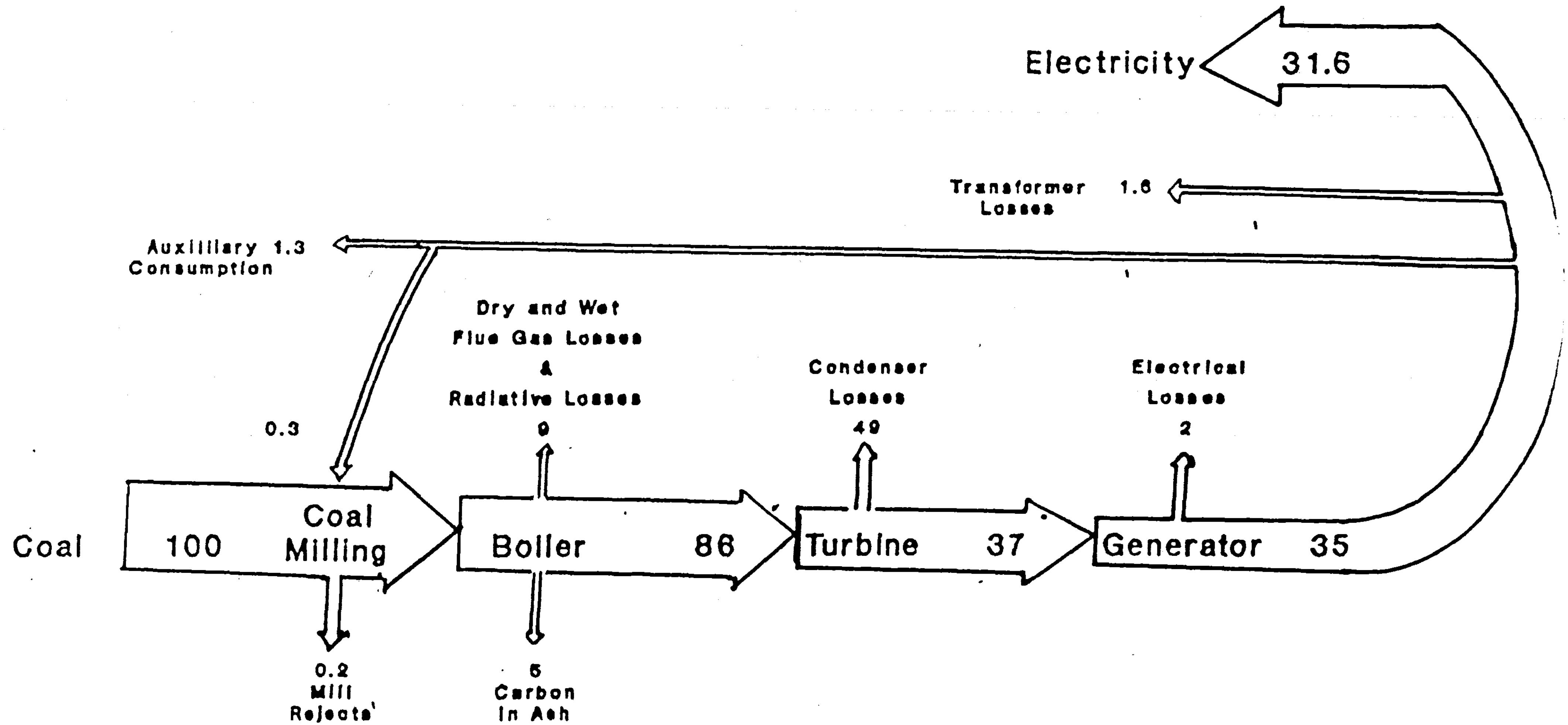

Fig. 2: Energy Flow Diagram for a Pulverized Coal Boiler - Steam Turbine Power Station

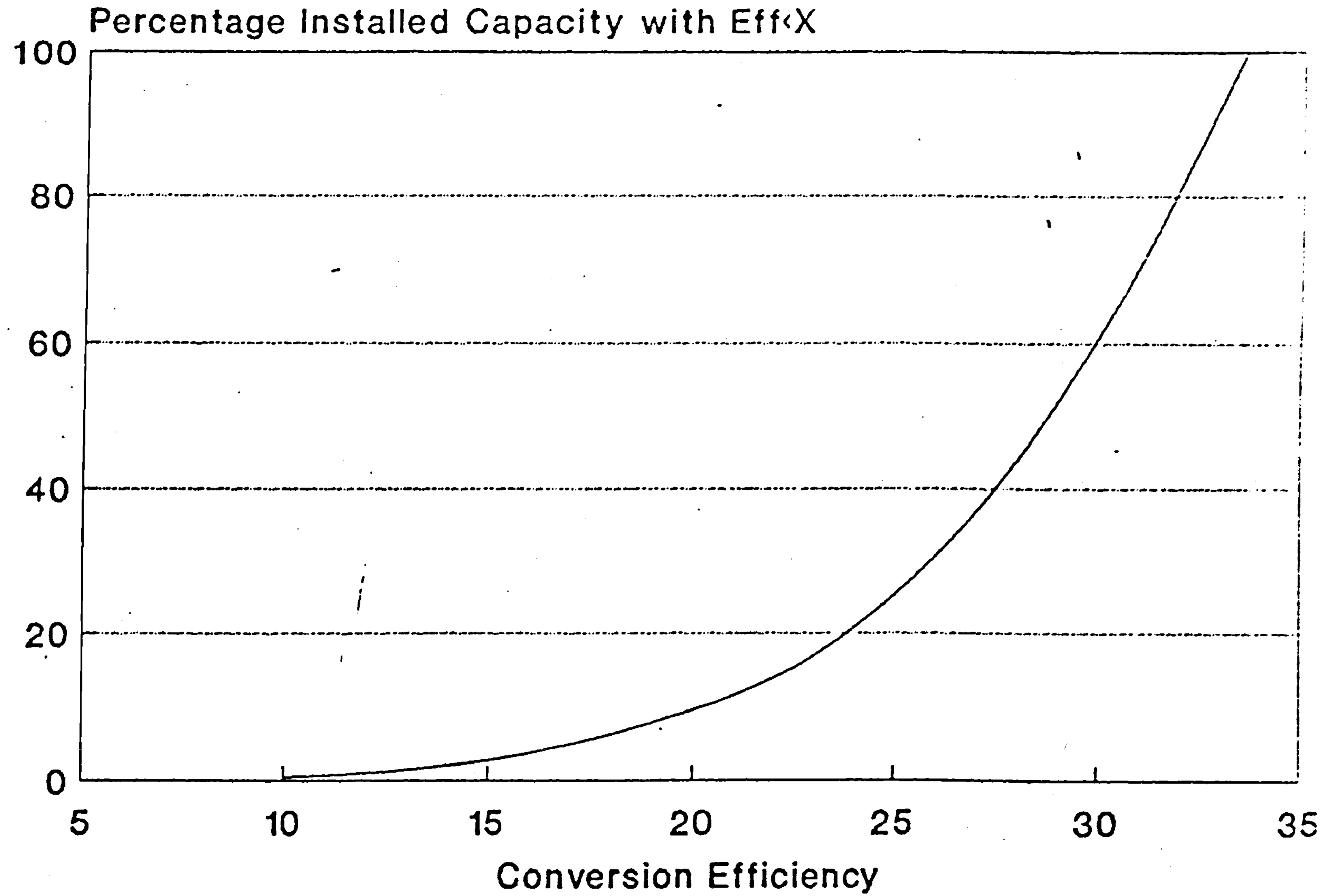

Fig. 3: Distribution of Station Efficiency as a Function of the Coal-Based Thermal Installed Capacity, 1986-87

The major losses occur in the turbine. the boiler, and auxiliaries. Much of the loss is due to poor operating practices such as unnecessary use of fuel oil for flame stabilization, steam pressure excursions, high excess air, inefficient ejector operation, poor quality of water supplied to turbine condensers, and inappropriate angle of burners in boilers. Improper maintenance of coal mill, insulation and high pressure heaters is another leading cause for low efficiency. Training of both operators and supervisors, and regular energy audits with associated responsibilities for optimal plant operation would improve plant performance. These require upgradation of managerial capabilities and financial stability. Currently, the cumulative losses of electric utilities in India are estimated to be about Rs.32.35 billion, and increasing at about Rs.3 billion per year. These have lead to poor maintenance and, arguably, to a decline in managerial efficiency. Low tariffs and poor revenue realization (as well non-optimal system expansion) are cited as the main causes of the continuing financial losses, and it is improbable that upgradation of managerial capabilities or financial stability would be achieved unless tariffs are raised and revenue collection enhanced.

Tariff increases would impose a cost on the economy, but would probably result in improvements in the quality and quantity of electricity supply; which, in turn, would lead to enhanced productivity in the economy. Tariff increases represent the economically most efficient method for enhancing the efficiency of electricity generation in the country; it is, however, a political decision which has to be evaluated in terms of social and political acceptability rather than economic efficiency alone.

Technological improvements that can lead to efficiency enhancements in existing plants include replacement of existing components by more efficient versions such as tower-type boilers, regenerative turbines, and ball mills. Washing of non-coking coal is another technology that can enhance generation efficiency. Many existing units were designed for comparatively low-ash coals, say 30%, and are receiving coal with higher ash content, typically 40%. Because of this deterioration in coal quality, combustion efficiency can decline as the boiler is optimized for lower-ash coal. Additionally, in all units (old and new), the mills require less power to grind washed coal. It should be mentioned here that washing is envisaged to primarily remove extraneous matter (such as shale) that comes with coal extracted by open-cast mining. Open-cast mining now accounts for more than two-thirds of the coal supplied to power stations, and this proportion is increasing.

It is difficult to exactly project the efficiency increases that would accompany the use of washed coal. The only experience with using washed coal for power generation is a month-long trial in a 210 MW unit at the Satpura power station of the Madhya Pradesh State Electricity Board

(National Productivity Council, 1988). Salient features of the washed and unwashed coals and performance indicators while using these types of coal are shown in Table 3. The boiler was designed to burn coal with calorific value of 4400 to 4500 kCal/kg, but calorific value of received coal had deteriorated to 3637 kCal/kg a the time of the trial, thereby resulting in effectively derating the boiler to about 82% of its design capacity, or 192 MW.

Table 3: Salient Features of the Trial Using Washed Coal at Satpura

	Washed Coal	Raw Coal
1. Coal properties		
Fixed carbon, %	39.57	31.87
Ash, %	31.69	39.83
Alpha Quartz, %	14.5	11
Calorific Value, kCal/kg	5604	3949
2. Boiler Efficiency, %	89.5	86.5
3. Coal Consumption, kg/kWh generated	0.553	0.767
4. Specific Fuel Oil Consumption, ml/kWh generated	0.3	5.023
5. Gross Heat Rate, kCal/kWh	2802.7	3068.1
6. Specific Auxiliary Power Consumption, kWh/kWh generated	0.073	0.088
7. Unit Heat Rate, kCal/kWh generated	3023.4	3364.1
Unit Efficiency, %	28.4	25.6
8. Specific CO_2 emission, kg CO_2/kWh delivered	0.866	0.983

Source: National Productivity Council, 1988.

The trial indicated that unit efficiency increased from 25.6% to 28.4%, and specific CO_2 emission decreased from

0.983 to 0.866 kg CO_2/kWh delivered, as a result of using washed coal.

At present, there are no washeries for non-coking (power grade) coal in India. The principal reason for their absence is the lack of capital to put them up. A washery for a 1040 MW TPS is expected to cost Rs.320 million (Rs.260 million at 1987 prices, Planning Commission, 1988), and annual O&M expenditure to produce 3 million tonnes of washed coal is expected to be about Rs.85 million. The additional cost due to washing is about Rs.40 per tonne of washed coal. The net efficiencies imply that 1kWh of delivered electricity require 0.84 kgs of raw coal and 0.597 kgs of washed coal. The additional cost of 0.597 kgs of washed coal is Rs.0.239, while the reduction in CO_2 emissions is 0.117 kgs. The cost of reduction is, therefore, Rs.2.04 per kg CO_2.

It should be emphasized here that since no non-coking coal washery is in operation presently, their performance and economics is not established. However, to a first approximation, the cost of CO_2 reduction due to coal washing can be taken to be Rs.2/kg CO_2.

Nitrogen Oxide Control

The oxidation of nitrogen compounds in the coal and of molecular nitrogen in the combustion air produces nitrogen oxides. Most of the advanced combustion concepts and modification techniques are directed towards preventing the formation of high temperature zones since NO_x formation is accelerated at high temperatures. A fuel rich initial combustion zone is established in which the fuel nitrogen can be oxidized to molecular nitrogen, rather than to nitric oxide. Thus, all of the combustion modification techniques except flue gas recirculation (FGR) depend on reducing the availability of oxygen in the primary combustion zones.

Combustion modification techniques such as low excess air firing and staged combustion have been shown to be effective in reducing nitrogen oxide emissions from coal combustion. In low excess air firing, the unit operates at a reduced level of total combustion air flow while maintaining acceptable flame and furnace conditions. There are three methods of staged combustion:

1. Biased, or off-stoichiometric firing: the air/fuel mixture in the boiler is stratified, and part of the combustion air is diverted outside of the initial fuel/air mixing zone.
2. Burner-out-of-service operations: the fuel flow to an individual burner is cut (while maintaining the air flow).
3. Overfire air ports: part of the combustion air enters by ports above the burner to generate fuel-rich conditions at the burner.

In FGR, gas is taken from the exhaust stream and reintroduced in the furnace. This technique has often been used for steam temperature control; however, few coal-fired units use FGR.

Both nitrogen oxide production and the effect of combustion modifications in reducing it depend on how the furnace is fired. While modification techniques can significantly reduce nitrogen oxide emissions, more advanced concepts, such as new burner design (which can be retrofitted onto existing units) or flue gas treatment, are required to achieve very low levels of nitrogen oxides. Table 4 shows that up to 60 percent reduction in nitrogen oxide emission can be obtained by combustion modification.

Table 4: Percent Variation in NO_x Control Efficiencies of Combustion Modifications With Method of Coal Firing

Control Method	Firing					
	Single-Face		Horizontally Opposed		Tangential	
	Typical	Maximum	Typical	Maximum	Typical	Maximum
Low excess air	0-15	15	0-15	15	0-10	10
Biased firing	5	7	5	8	--	--
BOOS	30	35	25	30	30	45
Overfire air	15	30	30	58	30	35
Recirculation	--	--	14	17	--	--
New burners	--	--	30	60	--	--

An USEPA inventory of utilities using combustion modifications to reduce nitrogen oxide emissions in response to NSPS or local regulatory requirements showed that 54 use factory-installed new burner designs or overfire air, 2 use retrofit new burner designs and overfire air ports, and 1 uses the burners-out-of-service method. An additional 117 "planned" coal-fired installation will use combustion modifications. The control methods reported for these facilities again include overfire air and new burner designs.

Table 5 gives available cost data for new and retrofit combustion modifications for a 210 MW unit. Capital costs are difficult to assess because of the limited data and the unique character of each unit, especially for retrofit applications. The size of the unit is also an important factor. As shown in Table 5, costs range from negligible for low excess air firing to almost Rs. 27 million for

Table 5: Capital Cost for Combustion Modification Methods for NO_x Control (for a 210 MW Unit)

	Firing Method		
	Single Face	Horizontally Opposed	Tangential
Control Method	Cost (Million Rs.) New/Retrofit	Cost (Million Rs.) New/Retrofit	Cost (Million Rs.) New/Retrofit
Lower Excess Air	0/1.75	0/1.75	--
Biased Firing	--	--	--
Burners out of Service	--	--	--
Overfire Air	0.55/2.05	0.55/2.05	0.55/2.05
FGR	--	3.23/4.91	--
New Burners	4.10/27.30	4.10/27.30	--

retrofitting new burner designs. The effect on the cost of power will be about 0.6 p/kWh increase for retrofitted new burners.

The installation of new burners would decrease Nox emission by 2.5 grams of NO_x/kWh; the cost of NO_x reduction is, therefore, of the order of Rs.25/kg of NO_x.

Combustion modification techniques can reduce the NO_x emission level to a minimum of about 0.6 gm/m³. For further reduction in NOx emission levels (e.g. the emission standard of 0.2 gm/m³ in FRG) catalytic converters are installed between the ESP and the stack. Ammonia is supplied to these units and catalytic reduction of NOx molecular nitrogen occurs. There is considerable pressure drop across these units and their operating and capital cost is expected to be 2% and 10% respectively of the boiler-turbine system. This would increase electricity cost by about Rs.0.1/kWh, and reduce NO_x emissions by about 5.5 gms/kWh. Control cost is, therefore, Rs.20/kg NO_x.

Advamced Technologies for Power Generation from Coal

There are many technologies that have the potential for replacing pulverized-coal combustion as the primary coal-to-electricity technology. Fluidized-bed combustion (FBC) is already commercially available at capacities upto about 150 MW; Integrated Gasifier Combined Cycle (IGCC) technology is being tested for techno-economic viability; Pressurized Fluidized Bed Combined Cycle (PFBCC) is undergoing technological development; and Integrated Gasifier Molten Carbonate Fuel Cell (IG MCFC) technology is still at the pre-pilot plant stage. These technologies are evaluated here in the perspective of their applicability for use with Indian coals, their efficiency and cost of electricity generation, and potential for specific CO_2 emission reduction.

Fluidized Bed Combustion

A diagram of a fluidized-bed boiler and power system is given in Figure 4. The particles in the fluidized bed consist not only of burning coal and ash, but are also other additives such as limestone or even sand. The concentration (inventory) of coal in the bed is fairly low. Limestone is used as an additive during the combustion of high-sulphur coals and absorbs the SO_x produced thus dispensing of the need for a separate FGD plant.

Air is introduced into the bed and bubbles through it, reacting with the carbon as it rises and producing heat. The gaseous combustion products leave the bed at the operating temperature, which due to the vigorous mixing does not vary significantly inside the bed. This usually means that 60% of the heat is transferred to boiler tubes containing steam which are submerged in the bed. Therefore 40% of the heat content of the coal leaves with the combustion gases and must be recovered in the superheater and economizer sections of the boiler. The vigorous mixing of solids particles ensures good combustion; consequently, coal with very high ash content can be effectively burnt in the bed. The inbed heat

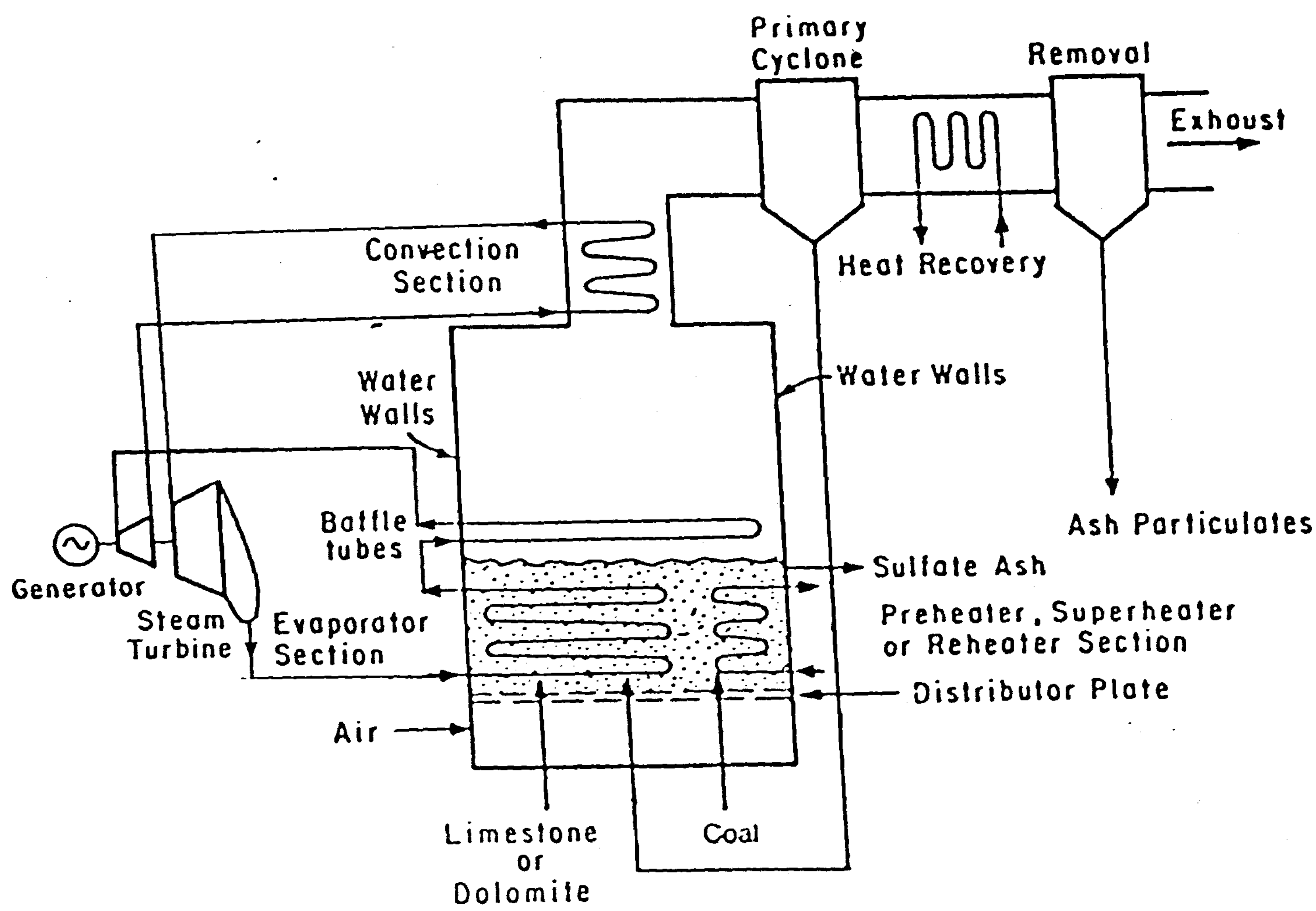

Fig. 4: Schematic Diagram of a Fluidized Bed Boiler - Steam Turbine Power Station

transfer tubes carry heat away very efficiently and the bed temperature can therefore be restrictd to about 800 to 900 K.

There are presently over a hundred industrial fluidized bed boilers in operation in India. Several small (less than 30 MW) FBC power plants are also in operation or under erection.

The net heat rate of large (greater than 200 MW) FBC power plants is expected to be of the order of 2650 kCal/kWh, or an overall efficiency of about 32.5%. The largest increases in efficiency occur due to reduction in flue gas losses (because of better heat transfer) and decrease in energy required for coal crushing (coal is crushed to 2 to 3 mm size, rather than 75 microns as in pulverized coal combustor). The combustion efficiency, however, is less than for pulverized coal boilers.

The cost of electricity generation is also estimated to be less than for pulverized coal plants, primarily due to lower O&M expenses. CO_2 and NO_x emissions are expected to be about 0.77 kgs CO_2 and 3 grams NO_x per kWh delivered.

The technology has to be developed at the large-scale capacity level to be adopted by the power industry in India. It is recommended that a 100 MW unit be installed and commissioned at the earliest so as to seek operational experience on this technology.

Advanced Technologies

Schematic representations of the three advanced technologies, as well as of the conventional pulverized coal boiler/steam turbine technology, are shown in Fig. 5. For conceptual convenience, each of the technologies has been split into three units: fuel processor (FP), primary conversion device (PCD), and secondary conversion device (SCD). The fuel processor converts coal into a form which can be utilized by the primary conversion device. The primary conversion device generates the bulk of the electricity produced, while the secondary conversion device extracts energy from the PCD waste heat to generate the additional electricity.

Both PFBCC and the conventional technology utilize coal directly and do not have FP units. IGCC and IG-MCFC systems, however, first convert coal into coal gas, and then convert this gas into electricity in the PCD. In both the latter systems, coal is required to be converted to medium calorific value gas (with calorific value of about 2,300 kCal/cu.m.) which primarily contains hydrogen and carbon monoxide. For Indian coals, dry ash, moving bed gasifiers (such as Lurgi) seem to be the most suitable to produce such gas. These gasifiers have efficiencies lower than those of many other presently available commercially, but the properties of Indian coals (primarily their high ash content, high ash fusion temperature, and low swelling and caking characteristics) severely restrict gasifier choice. Lurgi

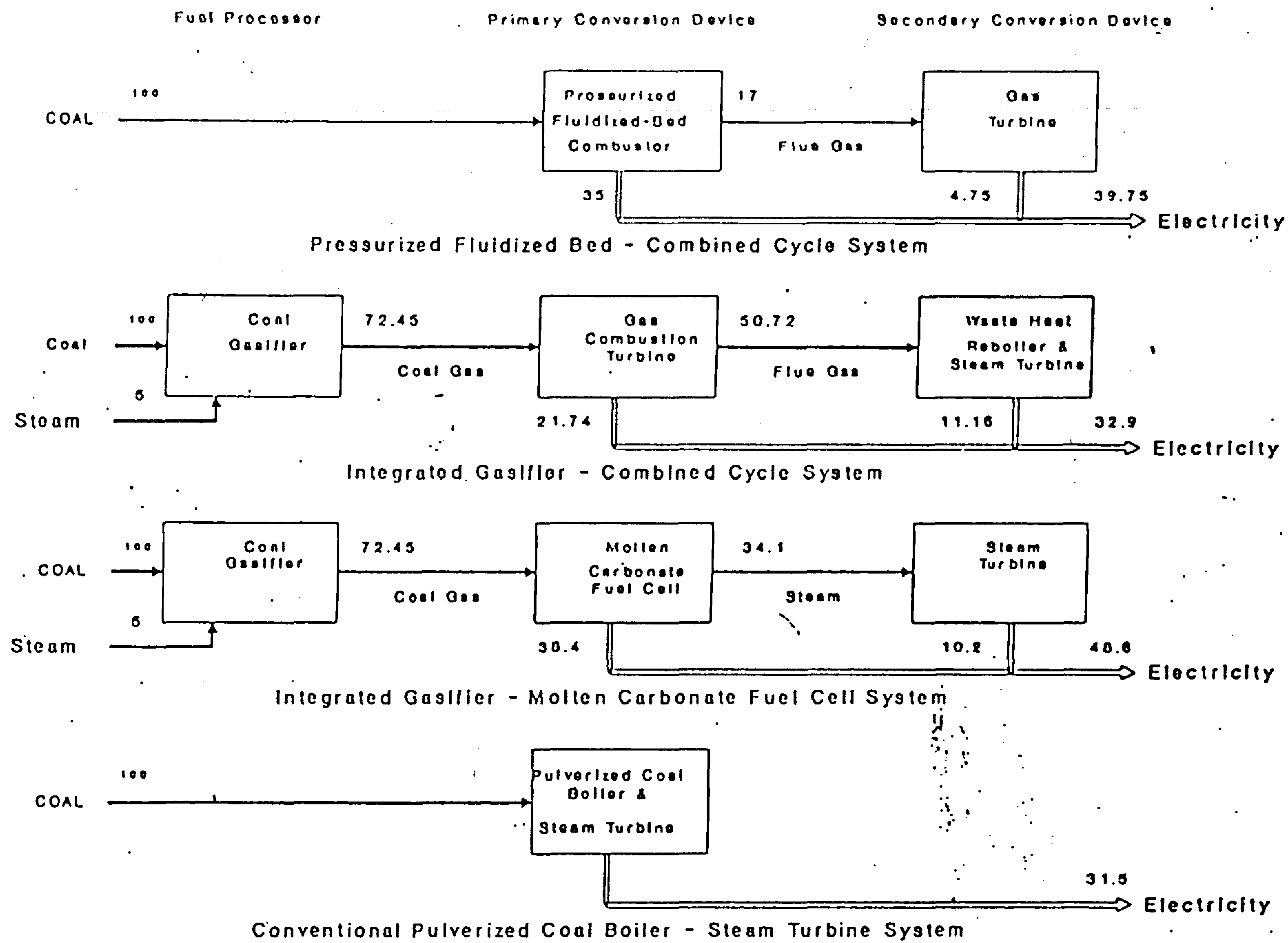

Fig. 5: **Block Diagram showing Conceptual Configuration of Advanced Coal Conversion Technologies for Power Generation**

gasifiers have been in commercial use internationally for nearly half a century, but have yet to establish a large commercial market.

The boiler-steam turbine combination constitutes the PCD in both conventional and PFBCC systems. The difference is in the type of boiler (coal combustor): conventional technology uses pulverized coal (PC) boilers, whereas PFBCC systems utilize pressurized fluidized-bed boilers. Coal is burnt under pressure in a fluidized bed in PFB boilers. Water tubes immersed in the bed generate steam. These boilers are inexpensive, have higher efficiency, and lower operating costs as compared to PC boilers. However, they are only incipiently commercialized, and the first two such systems are presently being set up. Consequently, information regarding their costs, and efficiencies is based primarily on pilot-plant data.

The gas combustion turbine constitutes the PCD in IGCC systems. This is a mature technology, albeit for use with natural gas rather than coal gas. The lower calorific value of coal gas (compared to 9,000 kCal/cu.m. for natural gas) effectively derates the gas turbine to one-fourth its rated capacity for natural gas and hence adds to capital costs.

In IG-MCFC systems, the coal gas is fed to a MCFC (the PCD unit) which electrochemically converts hydrogen into electricity. Carbon monoxide and methane in the coal gas are also converted to hydrogen before the coal gas is fed to

MCFC. No combustion occurs, and the conversion efficiencies (unrestricted by Carnot cycle limitations) are in the range of 47 to 59 per cent. Oxygen (or air) is also fed to the MCFC (which operates at temperatures around 700°C), and the electrochemical reaction leads to the production of high-pressure, high-temperature steam in addition to the direct generation of electricity. The technology is still under development, and as yet no pilot plants are in operation. However, it is expected that this technology will be commercially available by the mid-nineties. Costs and efficiencies for MCFCs are based on industry projections.

The conventional PC boiler-steam turbine technology produces low-quality waste heat which cannot be effectively utilized. However, the three advanced technologies considered here produce high-quality waste heat that is used to generate additional electricity through the SCD. In the case of the PFBCC system, the high-pressure high-temperature combustion gases emanating from the PFB boiler are used to drive a gas turbine. The major technical problem is the cleanup of the hot gases in order to ensure that particulates carried by them do not damage the gas turbine.

In the IGCC and IG-MCFC systems, a steam turbine is used in a bottoming cycle as a SCD. The hot combustion gases from the gas combustion turbine in the IGCC system are utilized to generate steam in a waste heat boiler (WHB). In the case of IG-MCFC system, high pressure steam is directly generated in the MCFC. The WHB and steam turbine are mature technologies which are already in extensive use.

In the perspective of the levels of technological and commercial development of the various units of these technologies, it is evident that there is a wide variation in the uncertainties associated with the parameters (costs and efficiencies) characterizing these technologies. Thus, while these parameters are well-established for PC boilers, gas and steam turbines and waste heat boilers, they are less firm with respect to PFB boilers and Lurgi gasifiers, and quite uncertain for MCFCs. Consequently, while single numbers are quite representative of parameters values for technologies in the first category (which are technologically and commercially mature), ranges of cost values (and single-number efficiency values) are more appropriate for technologies in the second category (incipiently commercialized), while only ranges of values can be specified for all parameters for the third category of technologies (in the developmental stage).

Economic Comparison of the Advanced Technologies

The cost of 3,600 kCal/kg coal is taken as Rs.0.25/kg which is the maximum pithead cost in India. Table 6 lists the value, or range of values, for efficiency and cost parameters for the three technologies. The expected values and their standard deviations are also listed in Table 6.

Table 6: Values of Cost and Efficiency Parameters for the Advanced Technologies (at the utilization scale of 1 million tonnes of coal per annum)

Parameter	PFBCC System			IGCC System			IG-MCFC System		
	Value	Expected Value	Standard Deviation	Value	Expected Value	Standard Deviation	Value	Expected Value	Standard Deviation
FUEL PROCESSOR									
Efficiency	1	1	0	0.63-0.75	0.69	0.02	0.63-0.75	0.69	0.02
Capital Investment, Rs./MCMH	0	0	0	54-76	65	3.666	56-80	68	0.0167
Annual O&M Rs/MCMH-Yr	0	0	0	1.34-1.40	1.37	0.01	1.40-1.50	1.45	0.0167
PRIMARY CONVERSION DEVICE									
Efficiency	0.33-0.37	0.35	0.0067	0.30	0.30	0	0.47-0.59	0.53	0.02
Capital Investment, Million Rs./MW	9.3-11.7	10.5	0.4	9-12	10.5	0.5	6.7-15.7	11.2	1.5
Annual O&M, Million Rs./MW	0.185-0.235	0.21	0.0083	0.18-0.24	0.21	0.01	0.205-0.425**	0.315	0.0367
SECONDARY CONVERSION DEVICE									
Efficiency	0.039-0.056*	0.0475	0.0028	0.22	0.22	0	0.27-0.33	0.30	0.01
Capital Investment, Million Rs./MW	13.2-15.8	14.5	0.4333	18-20	19	0.333	18-20	19	0.333
Annual O&M Million Rs./MW-Yr	0.4-0.55	0.475	0.025	0.45-0.51	0.480	0.01	0.45-0.51	0.48	0.01
Operating hrs/Yr	6000	6000	0	6500	6500	0	6500	6500	0
F_A	0.025	0.025	0	0.020	0.020	0	0.02	0.02	0
Life Yrs	30	30	0	30	30	0	20	20	0
Annual Capitalization Factor	0.124	0.124	0	0.124	0.124	0	0.134	0.134	0

*Gas turbine efficiency is 28 per cent. However only the flue gas waste heat (14-20 per cent) is directed to the turbine while the steam turbine waste heat (43-53 per cent of the total coal heat input) is discharged to the atmosphere.
**Annual O&M includes replacement of electrodes after every ten years.

Table 7: Comparison of Efficiencies and Costs of Generation for the Various Technologies

Technology	Efficiency (%)		Pithead Cost of Generation (Rs./kWh)	
	Expected Efficiency	Standard Deviation	Expected Cost	Standard Deviation
PFBCC	38.09	0.66	0.431	0.00871
IGCC	31.33	0.91	0.504	0.00892
IG-MCFC	46.30	1.72	0.458	0.0263
PC Boiler/ Steam Turbine	31.50	0	0.672	0

Table 8: CO_2 and NO_x Emissions from Advanced Technologies

	CO_2 Emissions, kg/kWh		NO_x Emissions, gms/kWh
	Expected Value	Standard Deviation	
PFBCC	0.911	0.016	1.42
IGCC	1.167	0.034	0.43
IG-MCFC	0.778	0.029	0.29

Conclusions

In the short-term, efficiency improvements in pulverized coal power plants would decrease total CO_2 emissions. Improved operating and maintenance procedures would yield the fastest returns in terms of efficiency improvements, but it is doubtful whether these can be implemented unless financial stability is achieved. The latter would require, amongst other things tariff increases which are politically and socially difficult to enforce. The most robust solutions seem to be technological upgradation of power plant components (boilers, ejectors, coal mills, turbines, etc.), and the washing of coal supplied to power plants. The latter is expected to reduce CO_2 emissions at a cost of about Rs.2/kg of CO_2.

The control and reduction of nitrogen oxides can also be primarily achieved by good operating practice, principally low excess air and reduction in oil support for flame stabilization. Combustion modification techniques can lead to reductions of upto 30% in NO_x emissions. Replacement of burners by improved designs can lead to reductions of upto 50%; the specific cost of reduction would be the order of Rs.2.5/kg of NO_x. Catalytic reduction of NO_x can reduce emissions by about 85%; the cost of reduction then increases to about Rs.20/kg of No_x..

Fluidized-bed combustors seem to be the best alternative to pulverized coal boilers in the medium term. FBCs cost as much as pulverized coal boilers, require less annual expenditure, are more efficient, and have lower specific emissions of both CO_2 and NO_x. They are, however, presently available in capacities upto about 150 MW only. There is an urgent need to upscale this technology to the 200-500 MW level, and also to immediately introduce 100 MW FBCs at a number of stations in the country so as to start gaining operating experience.

In the long term, IG-MCFC is potentially the most efficient and inexpensive advanced coal-to-electricity technology. However, it is still in the developmental stage and at least half a decade away from demonstration level operation. As expected, the largest uncertainties, both with respect to overall efficiency and expected cost of electricity are associated with this technology: the single-largest uncertainty being that due to the capital cost of the MCFC.

PFBCC technology is next best, both in terms of efficiency and electricity cost. The uncertainties associated with PFBCC cost and efficiency parameters are much smaller than those associated with IG-MCFC systems, and the single largest uncertainty is due to PFBC capital cost. This is primarily due to uncertainty in costs of gas cleanup devices which are capable of conditioning the PFBC flue gas to meet gas turbine inlet standards.

The IGCC system is the only advanced coal utilization technology which has already entered the commercial market.

It produces electricity at costs substantially lower than those of conventional coal-based power plants (but higher than those of the other two advanced technology), but its efficiency is marginally less than that of conventional plants.

In the perspective of the levels of technological and commercial development of these technologies, their efficiencies and costs of electricity generation, and the scarcity of financial resources in India, a long-term strategy for the introduction of these technologies into the Indian market is developed in the following.

In the short-term (5 years), IGCC system should be installed in an increasing percentage of the added capacity and all retrofit/renovations of existing capacity. With the expected addition of about 20,000 MW of coal-based electricity generation capacity during the 8th Five Year Plan (1990-1995), the share of IGCC systems must reach the 5,000 MW mark. This will decrease the capital requirement of the thermal electricity programme by about 10 per cent and create a work force trained in the operation of gas turbines and coal gasifiers. It will also add to the peaking electricity capacity in the country which is presently far short of the desired system optimum owing to delays in the addition of hydro-electric capacity. During the 5-year period, an intensive systems engineering effort should be launched so as to develop commercially viable PFBCC systems by 1995. A similar R&D effort - but with much larger funding - should be launched to develop commercially viable IG-MCFC system by the turn of the century.

In the medium time frame (1995-2000), the PFBCC system should be introduced into the market so that it constitutes at least 50 per cent of all new capacity added in the year 2000. During this time frame, IGCC systems should maintain their 25 per cent share of new capacity additions.

The IG-MCFC systems should start entering the market in the beginning of the 21st century. Gasifier operating experience of about ten years will be available by that time, but the entirely new MCFC technology will lead to a comparatively modest market entry for the first five years. Beyond 2005, both IGCC and conventional systems should be discontinued, and only PFBCC and IG-MCFC systems added to the coal-based thermal power capacity. This 15-year transition will probably result in a 25 per cent reduction in capital costs, a 10-20 per cent increase in overall conversion efficiency, and a 25-35 per cent decrease in electricity costs.

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